Foreword

The authors of this report are David Olivier and John Willoughby who were contracted by BRECSU, on behalf of the then Energy Efficiency Office, to investigate and report on ultra-low-energy dwellings in the UK. The purpose of the investigation was to assess how many homes of this type have been constructed and their potential for wider replication. In order to provide a complete picture, relevant details of all homes investigated are included in this report. It should be appreciated that some of the measures do not represent cost-effective options, and their inclusion does not imply recommendation by the DOE. The contributions from Robert Lowe and Derek Taylor, who assisted the authors is gratefully acknowledged.

Additionally, the authors are very grateful to the many designers and owners who gave permission to reproduce copies of their construction drawings, photographs and other copyrighted material in this report.

The authors have made every effort to be accurate in their reporting of the material supplied to them. However, they accept full responsibility for any misinterpretations they may have made.

contents

Lower Watts House, Charlbury, Oxfordshire

Summary

This is Phase 2 of a review into ultra-low-energy homes carried out under the DOE's Energy Efficiency Best Practice programme in 1994. It contains ten detailed profiles of low-energy UK housing schemes. They cover a wide geographical area and a variety of construction methods.

Many issues arise as a result of reviewing the ultra-low-energy schemes in Phases 1 and 2. These are listed after the separate profiles. The report contains 23 wide-ranging conclusions derived mainly from this study.

By taking appropriate steps, it may be possible for the UK to make more rapid progress with ultra-low-energy dwellings. Eventually, some of the lessons from these examples might be integrated into general building practice.

This report is targeted at architects, designers, housebuilders and anyone interested in the design and construction of low-energy homes.

Schemes profiled in Phase 1 of this review are contained in General Information Report (GIR) 38.

The main conclusions

There is now a significant amount of UK activity in the area of ultra-low-energy homes. Forty UK schemes were profiled in Phase 1 of this review, and a further 34 schemes were identified.

The schemes contained in Phase 1 account for over 500 homes. They show that high levels of energy efficiency can be achieved with a wide range of construction methods and techniques.

At the same time, 12 overseas schemes were reviewed, and another 18 were identified. Some of the 12 schemes are located in more severe climates than the UK. Nevertheless, their energy consumption is impressively low.

Only a small minority of the UK schemes have been fully monitored. In most cases, the exact results of applying the energy-conscious design features are not known.

Where UK schemes have been monitored, or where their electricity, gas and other fuel consumption has been measured by the owners, the performance is generally not as good as expected. Only four schemes meet the original target of this review. This was an energy use of less than 100 kWh/m^2yr. This can be compared to the consumption of the 12 overseas schemes, which is between 9 and 90 kWh/m^2yr in each case.

Two major factors contribute to the poor performance of the monitored UK schemes. These are high air leakage rates and the poor design and/or commissioning of heating systems.

Introduction

This is Phase 2 of a review, (carried out under the DOE's Energy Efficiency Best Practice programme in 1994) into ultra-low-energy homes.

The Phase 1 report contains short profiles of 40 UK schemes and 12 overseas schemes, plus a brief note of 34 more UK schemes and 18 from abroad.

The objective was not to select the ten 'best' schemes, but to choose an interesting and representative sample out of 40 very diverse projects. The broad criteria used in the selection of schemes included the following.

- Schemes which were built were given preference over schemes which were still on site. Projects which were at the design stage were excluded.
- Where the scheme had been built for a sufficient time, clear evidence should be available of a good energy performance.
- As far as possible, consistent with these earlier aims, a wide range of construction types should be covered.
- The scheme should not be covered extensively in existing literature or by reports which were in preparation. (Some schemes built in the 1970s and 1980s have been extensively described.)

The result of this process was the selection of ten schemes, of which:

- two were designed and built in the 1980s,
- two were designed in 1991-92 and built in 1992,
- four were built in the period 1993-94, and
- two were finished in 1995.

If the dwellings are classified by construction system, this gives the following breakdown.

- Schemes 1 - 5 – Cavity masonry walls. Different materials, including brick, stone, concrete block and concrete, and varying levels of thermal capacity. The wall insulation thicknesses range from 150 to 250 mm. All have Danish plastic wall ties and highly insulated window reveals, of several different types. Scheme 1 also has an interesting area of externally-insulated masonry wall.
- Schemes 6 - 9 – Timber-frame walls. Wall insulation thicknesses range from 150 to 240 mm. All but one are rendered or timber-clad. None have any internal thermal mass, except for the timber itself and the internal finishes. They illustrate a wide variety of framing methods, ranging from double walls of the Canadian type to the I-studs which are widely used in Sweden.
- Scheme 10 – An earth-sheltered dwelling with 100 mm of wall insulation. It is built into a south-facing slope, with a flat earth-covered roof, now comprising a lawn and flower beds.

Classifying the schemes by geographical area gives the following distribution:

- two in London,
- three in Wales,
- two in Milton Keynes,
- one in west Oxfordshire,
- one in Nottinghamshire, and
- one in Sheffield.

The map opposite shows the location of all the UK schemes.

A note on U-values

As noted in the Phase 1 report, the authors consider many of the stated U-values for schemes to be optimistic. Glazing gives rise to particularly great discrepancies.

The authors found no UK figures which appeared to overestimate heat loss. All the figures which appeared to be significantly optimistic have now been corrected and should now be fairly realistic. A few figures needing more minor corrections, of the order of 10%, may remain.

The U-values for vertical glazing allow for the effect of the frame and the edge-of-glass, which usually worsens the resulting U-value. Account has been taken of this and adjustments made to the U-values.

The quoted U-values for sloped double and triple glazing are in accordance with the ASHRAE 1993 Handbook of Fundamentals. These corrected figures differ from many estimates by allowing for thermal bridging via the frame, edge-of-glass and kerb, etc. UK calculations might give a marginally different result because of less extreme outside temperatures than in the USA, and perhaps a lower windspeed, but the amended values are considered much more realistic than some manufacturers' claims.

Conventions

The profiles follow a relatively standard format. The construction methods of the building are described first, followed by details of the building services. The environmentally beneficial measures which were incorporated in the design are then described, in addition to its energy-conscious aspects. Details of the costs and energy consumption, where these are known, are given.

A final section, entitled Experience/feedback, summarises aspects of the scheme which have worked particularly well, or which have given problems. Naturally, this section is longer and more detailed for schemes which were designed and built in the 1980s than for schemes which are still being constructed.

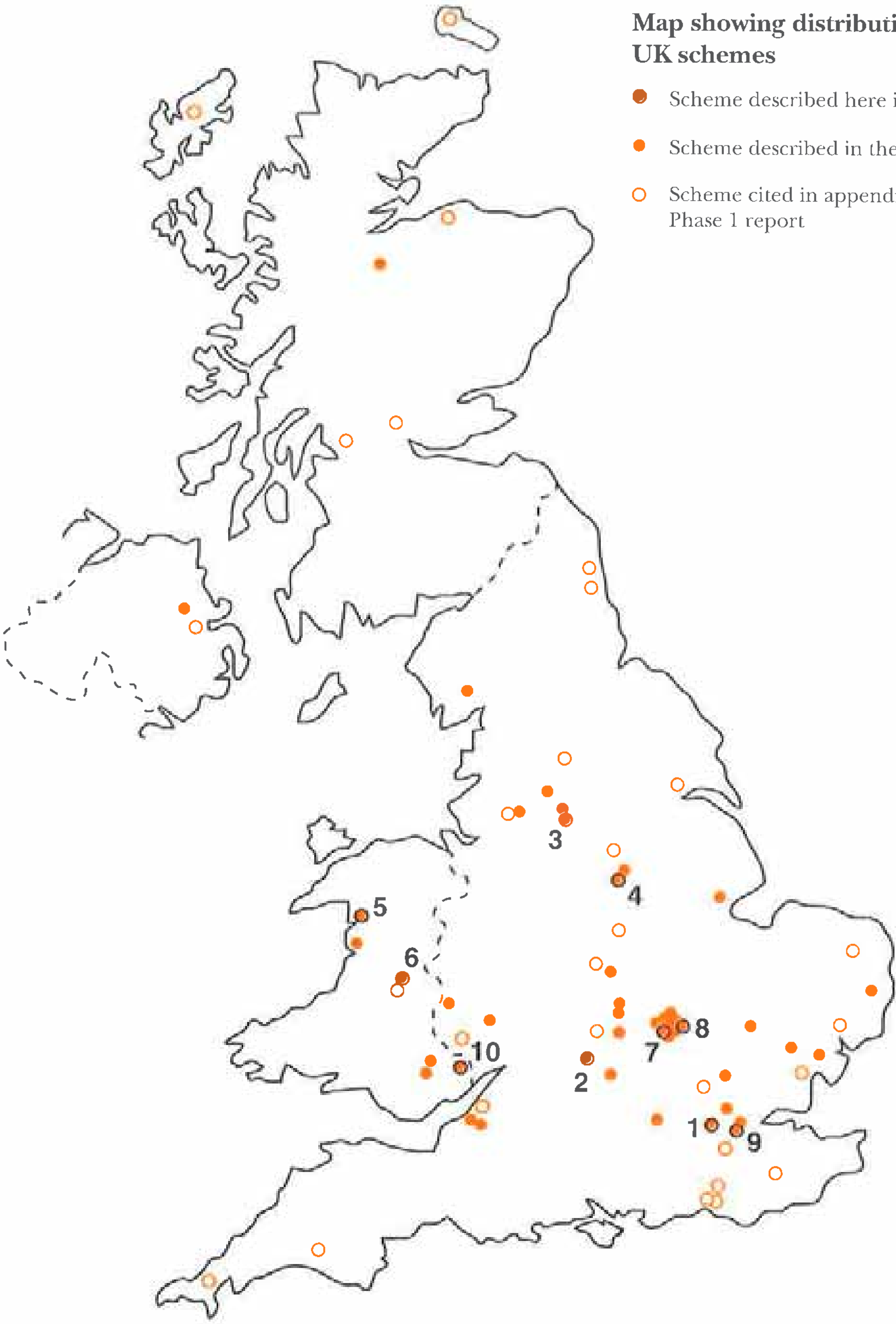
All the descriptions of wall, floor and roof constructions proceed from the inner face outwards.

conventions

The U-values of elements which are linked to the ground rather than the outside air, eg ground-bearing floor slabs and retaining walls, omit the thermal resistance of the earth and anything except the stated construction materials.

To calculate dwelling construction costs per unit floor area, a number of conventions were adopted. In all cases, the floor area has been measured over the house plan area, between the internal faces of external walls, and it includes all zones which have a ceiling height of more than 1.2 m.

The floor area excludes spaces which are not normally considered part of the main dwelling, such as garages, greenhouses, porches and cellars, whether they are insulated or not.

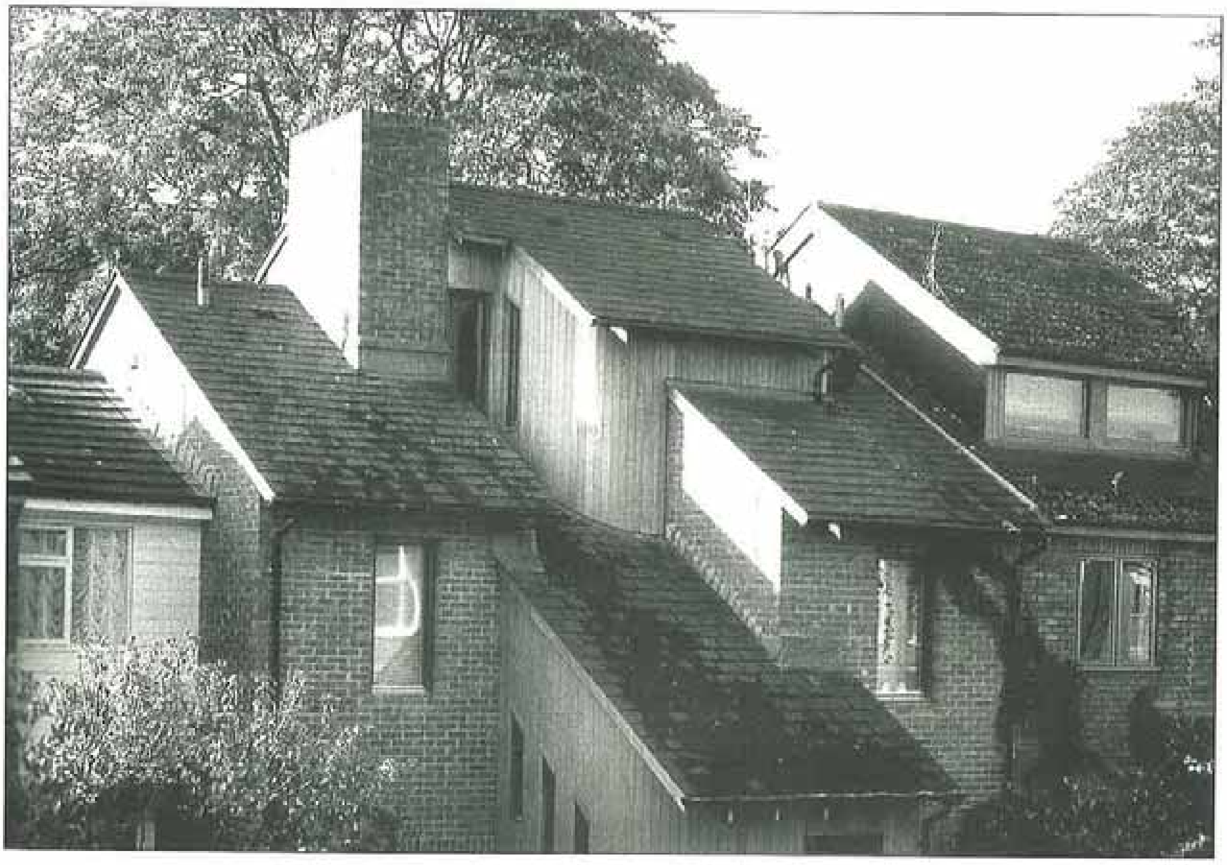


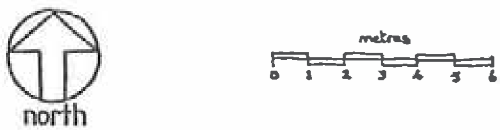
Map showing distribution of the UK schemes

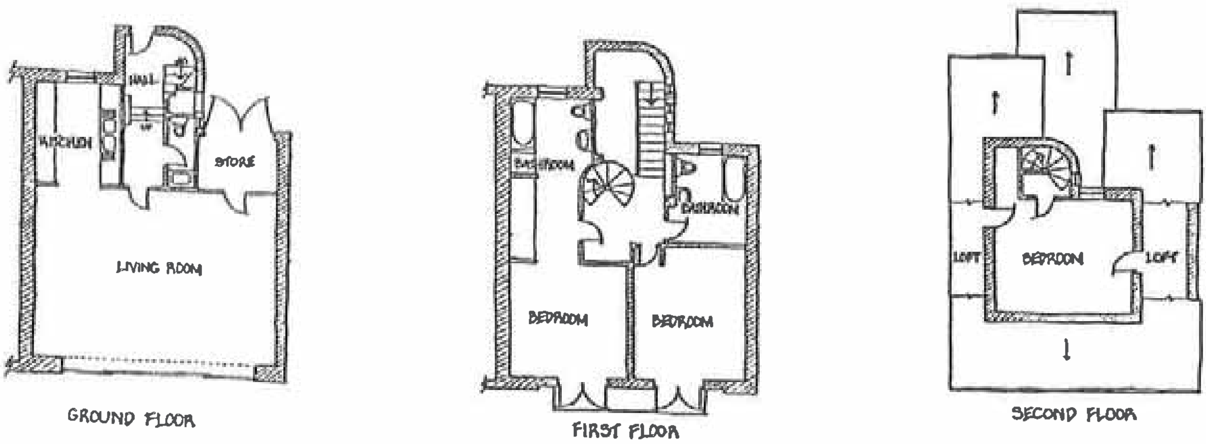
- Scheme described here in Phase 2
- Scheme described in the Phase 1 report
- Scheme cited in appendix of the Phase 1 report

MASONRY WITH CAVITY INSULATION / EXTERNALLY INSULATED MASONRY

Reyburn Residence, Glentham Road, London SW13 (1984-92)







Owner and Architect	Stephen Reyburn		
Energy Consultant	Energy Advisory Associates	**Structural Engineer**	Campbell, Reith and Hill

MASONRY

Reyburn Residence

Nature of the building

140 m^2 2.5-storey terraced infill house.

Three bedrooms, two bathrooms.

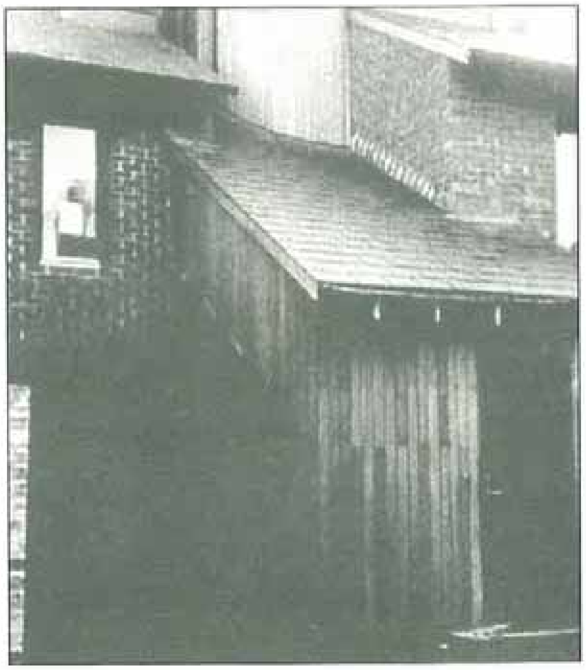
On a small urban plot, totally filling the gap between adjacent houses. The rear elevation faces due south.

Background

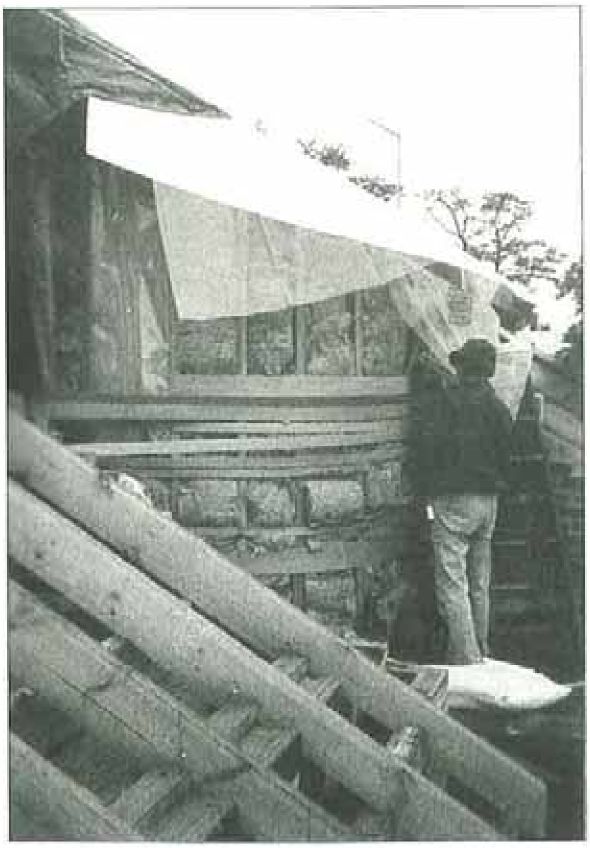
The project was conceived in 1984 but was built slowly, over a long period, on a direct labour basis, under the owner's supervision. The vast majority of items were installed by 1992.

The basic aim behind the design was to apply an integrated package of energy efficiency measures to UK masonry construction. The design was based on previous successful experience in Denmark and Sweden with very high insulation levels. Allowing for the differences in climate, the energy-related measures are similar to those seen in Danish low-energy houses of 1984.

The house has a complex shape. This made it a challenge to detail, in order to avoid thermal bridges. Examples of items which caused difficulty are a large curved section of wall on the front elevation, a curved reinforced concrete beam, a change in ground floor level, and a row of small second floor windows.



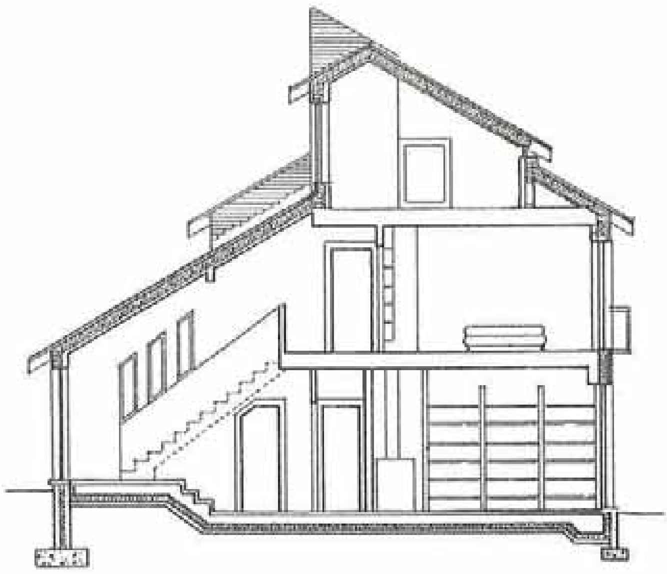
Rear entrance



External insulation being installed on curved wall

Fabric

Ground floor: Suspended concrete slab with 200 mm expanded polystyrene (U-value = 0.15 W/m^2K). The thickness of this reflected Danish advice at the time, and allows for the influence of the underfloor heating. This increases the heat loss from ground-bearing floor slabs.



Section

MASONRY

Reyburn Residence

Walls:

(1) 60% of area – Plaster, 102 mm common clay brickwork, cavity with 165 mm built-in mineral fibre batts and plastic ties, 102 mm facing brickwork (U-value = 0.21 W/m²K);

(2) 40% of area – Plaster, 102 mm single-skin clay brickwork, 75 mm mineral fibre, 100 mm mineral fibre between 50 x 100 mm timber studs, fixed to the rafters and supported off the brick, vertical timber cladding (U-value = 0.2 W/m²K);

(3) Party wall adjacent to neighbouring house of the same height – 50 mm mineral fibre in cavity wall (U-value = 0.55 W/m²K).

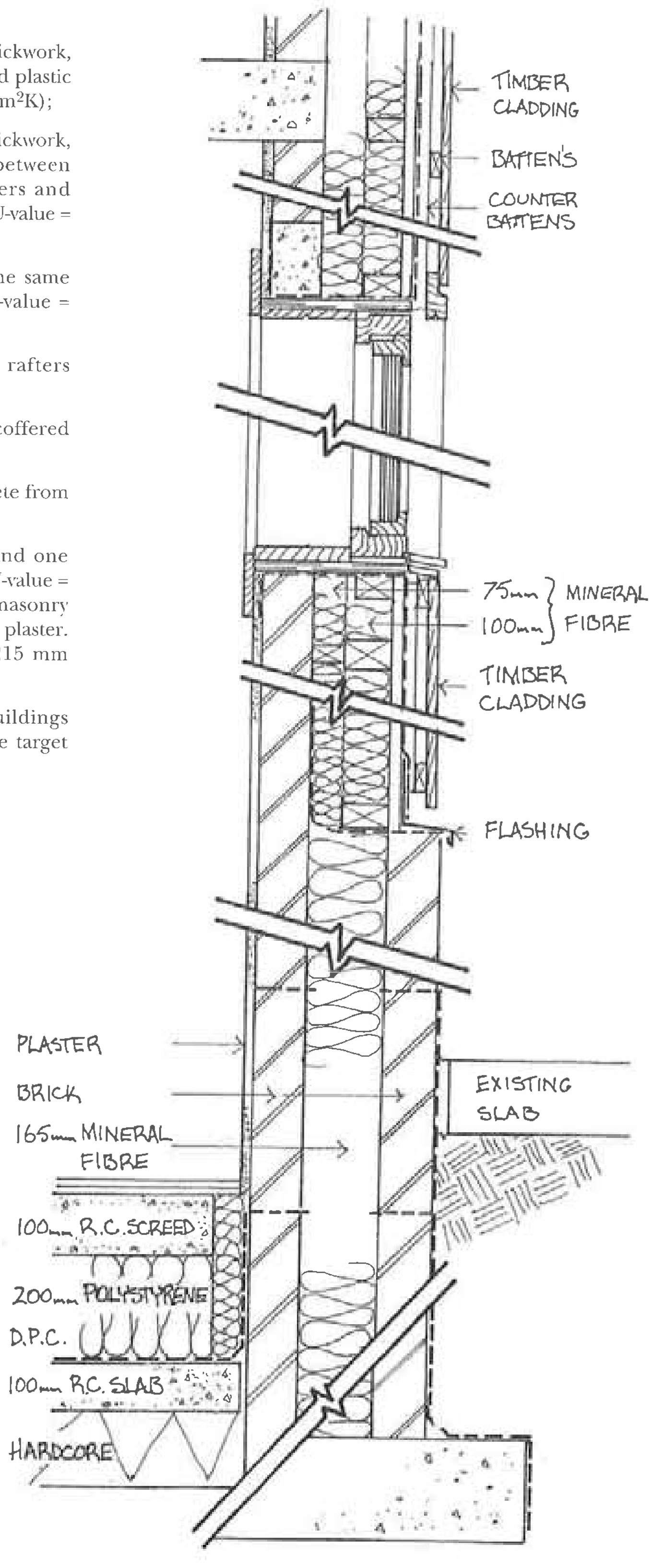
Roof: 250 mm mineral fibre between/below the rafters (U-value = 0.18 W/m²K).

First and second floors: 300 mm in-situ concrete, coffered ceiling.

Stairs: In-situ concrete up to first floor, precast concrete from there to second floor.

Windows: Of Swedish origin. 3-glazed with argon and one sputtered low-emissivity coating, in softwood frames (U-value = 1.5 W/m²K). Fitted in the openings using partial masonry returns and a plywood subframe, which is sealed to the plaster. A stainless steel angle supports the outer leaf; a 215 mm concrete lintel the inner leaf.

Air leakage: Given the performance of Swedish buildings constructed of similar materials at the same time, the target was 1 ac/h at 50 Pa, but it has not yet been measured.



Section through external wall, from ground floor to first floor level

MASONRY

Reyburn Residence

Services

Ventilation: Mechanical ventilation and heat recovery. System of Swedish origin, with a cross-flow heat air-to-air heat exchanger and circular steel ductwork. Fanpower at peak flow 150 W; less at normal speed.

Space and water heating: An 8 kW condensing gas-fired boiler on the second floor feeds an underfloor heating system and a 180 litre mains-pressure hot water storage tank. The underfloor controls package comprises a relatively crude room thermostat and a manifold sensor which further controls the flow to each loop of pipes. The room thermostat is temporarily placed in a bedroom cupboard but will eventually be moved to its permanent position, on the west wall of the living room. Piping covers the whole ground and first floors, but not the second floor. There is a secondary metal chimney and woodstove.

Cooking: Gas.

Lighting and electrical equipment: Some use of compact fluorescent lamps; installation still incomplete. Otherwise standard UK lights and appliances are used.

Energy consumption

The gas and electricity consumption has been measured for a three-year period, since the house was occupied. The table below indicates the average annual consumption over this period.

Energy carrier	Purpose	Usage kWh/m²yr
Gas	Space/water heating and cooking	90
Electricity	Ventilation, lighting and appliances	23
TOTAL		113

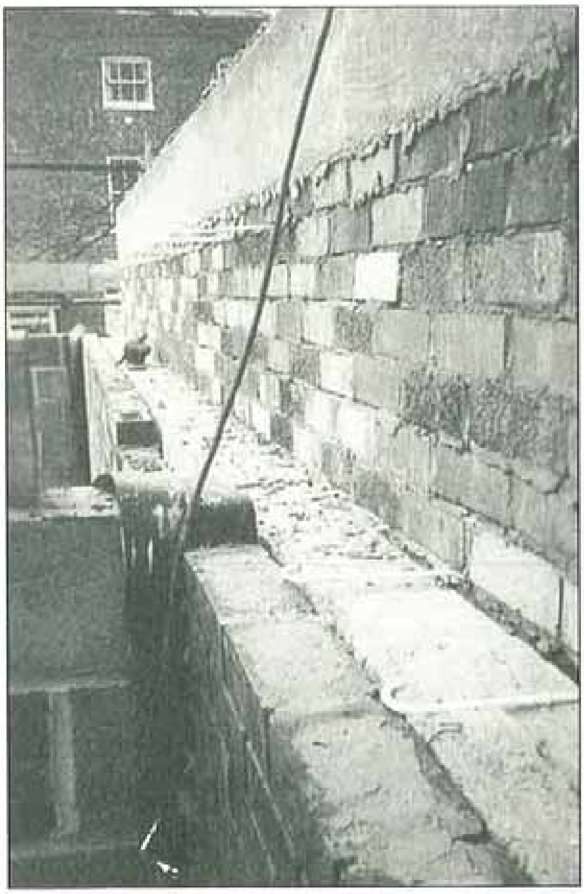
Measured energy consumption in the period 1991-94

Cost

Costs have been incurred over roughly an eight-year period. During this time, London building costs and tender prices have fluctuated widely. Until the owner prepares a final set of accounts, neither the total building cost nor the overcost are known.

Experience/feedback

The architect's impression is that the insulation materials were comparatively cheap but that great care was needed to reach a high level of airtightness, especially in the roof. This is partly because the concept is still so unfamiliar to UK builders. He considers that until operatives are better trained, the unfamiliarity will tend to make it relatively costly.



Early work on cavity wall, showing incorrectly-installed plastic wall ties

As the photographs show, the wall construction needed careful supervision in the early stages, until the operatives were familiar with the procedure for plastic ties and built-in mineral fibre batts. The first few square metres of cavity wall had to be rebuilt, with the ties inserted the correct distance. After that, construction proceeded smoothly.

The area of externally insulated single-brick wall gave no workmanship problems. In view of its economy in materials, it could well be recommended for wider use. The plywood sub-frames gave no installation problems, and have so far been trouble-free.The house's energy consumption for space heating is similar to that of contemporary Danish 'low-energy' houses. Many of these also appear to use low-temperature heat for space heating at a rate of 40-60 kWh/m²yr.

The underfloor heating has given less stable temperatures than predicted, although still less variable than in a typical UK house. Refinements may be made to the control system, but the first priority is considered to be an improvement to the thermostat. This is currently a relatively primitive device with excessive hysteresis and, as noted, is not yet located in its final site. A second measure may be a permanent reduction in the flow temperature. The area of heat emitters in the ground and first floor is greatly oversized for this house's peak heat loss.

MASONRY

Reyburn Residence

Cavity wall insulation being built into gable wall, with correct installation of wall ties

Despite this, the house has proved to be extremely comfortable. In most rooms, one is surrounded by relatively warm surfaces, and one is exposed to a radiant heat source. The owner believes that the comfort standard, as well as the low energy costs, are the greatest single benefits of this house compared to normal ones. He has taken a conscious decision to maintain comfort standards close to those observed in Scandinavia, rather than to keep the house at a more typical UK temperature and take most of the benefit in the form of savings on the energy bill.

The house was occupied in 1991, but it largely dried out in the period 1986-88. So, unlike some other masonry houses, this phase was entirely problem-free.

Since then, the Swedish mechanical ventilation system has given good service, preventing condensation. The amount of water extracted from the air by the ventilation system, which has a condensate drain, has been surprisingly small.

The ventilation system is reasonably quiet, but there is still an audible background noise. Having since seen the 'zero-energy' houses in operation at Wadenswil in Switzerland, the owner plans to fit a second silencer. This should make the sound imperceptible.

Although the house was designed to be airtight, some small air leaks are known to exist. In particular, some windows leak, especially one which was the subject of an attempted break-in. Although the Swedish supplier described the sliding patio door on the south wall as airtight, it does leak significantly, unlike hinged glazed doors from Sweden, which are very tight and had originally been recommended.

This house has a very high thermal capacity, as heavyweight as those on mainland Europe. Its thermal behaviour provides a contrast with the performance of more normal UK masonry buildings. The ground and first floors behave in a more heavyweight manner than the second floor, which is in contact with the concrete second floor and a masonry partition, but is mainly enclosed by the timber roof. When outside weather conditions change, the ground and first floor show a pronounced delay in heating-up or cooling-down.

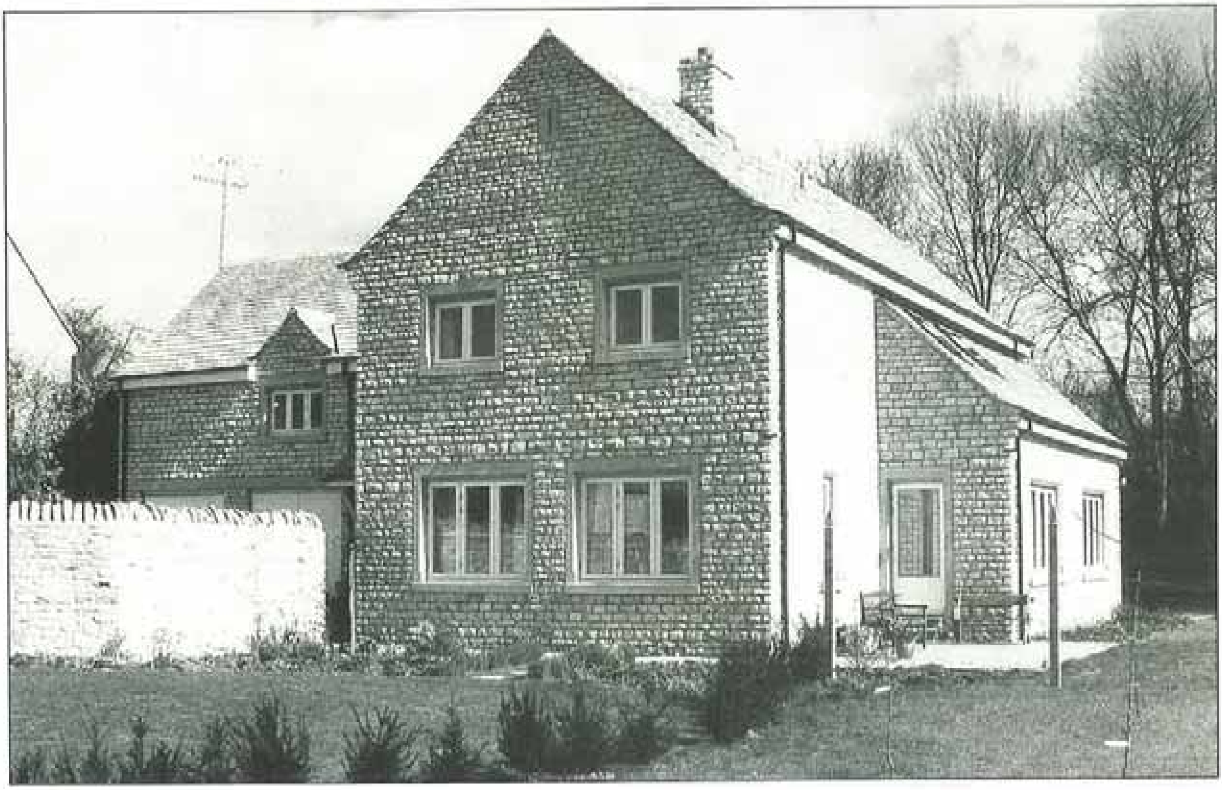
Linked to this, the high standard of summer comfort has been an added bonus, as the house was designed largely with UK winter conditions in mind. Even in prolonged heatwaves, the interior stays at a comfortable air temperature, in the range 22-24°C. This effect was particularly noticeable in the 1989 summer, which occurred after the structure and insulation were finished but while sub-contractors were still working on the house.

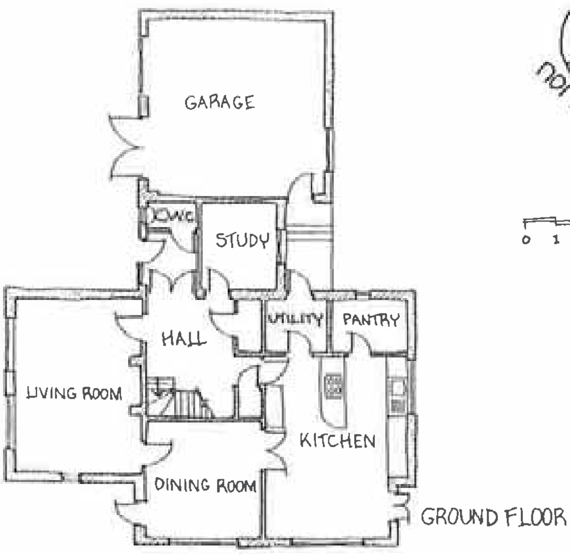
This performance is attributed to the high thermal capacity, the high levels of insulation, the lack of west-facing glazing, and a fortuitously sited deciduous tree. This tree shades most of the south facade in summer.

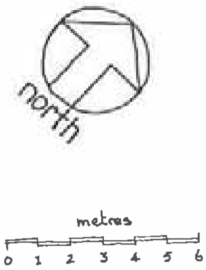
The electricity consumption of the house is not particularly low. The architect works from home, with a full range of office electrical equipment in use. It is expected to decline as more energy efficient lights and equipment are purchased.

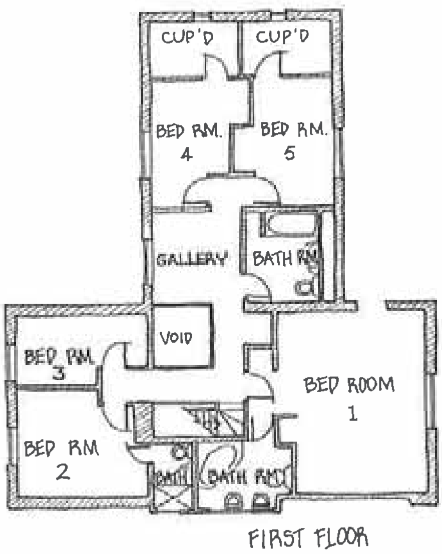
MASONRY WITH CAVITY INSULATION

Lower Watts House, Charlbury, Oxfordshire (1992)









Clients	Stephen Andrews and Liz Reason	**Architect**	David Woods Architects, Witney
Energy Consultant	Energy Advisory Associates	**Structural Engineer**	Passenger and Peachey, Witney
Air Leakage Test	EMC Ltd, Newport Pagnell, Bucks	**Builder**	Walkplace Ltd, Leafield, Oxon

MASONRY

Lower Watts House

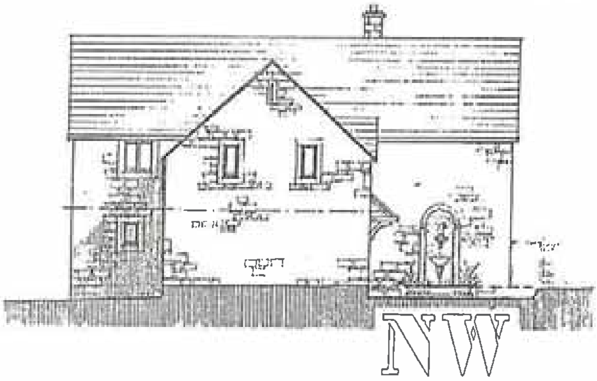
Nature of the building

290 m² 2.5-storey detached house, with double garage. Five bedrooms, three bathrooms.

The site is within the town's conservation area, surrounded by medieval stone buildings. The orientation is not ideal; the site has a good solar access to the south and south-west, but high trees to the east and south-east.

Background

The plot was purchased after a previous developer had gone out of business, leaving behind some half-completed foundations. The house made use of the majority of these existing works, but it was redesigned to make better use of passive solar gains. However, the design team took care to avoid controversial aspects which might delay the revised planning application, and for the same reason, to use only established energy efficient technology.



View from east

MASONRY

Lower Watts House

Fabric

Floor:

(1) Ground level – Suspended concrete beam-and-block, inherited with the foundations on the plot. 150 mm high-density expanded polystyrene above the deck and below the screed (U-value = 0.22 W/m^{2}K).

(2) Area above unheated garage – similar, with screed above 150 mm insulation.

Walls: Sand-cement plaster plus finish coat, inner leaf of 100 mm dense concrete block, cavity with 150 mm built-in mineral fibre batts and plastic ties, 150 mm Cotswold stone outer leaf (U-value = 0.22 W/m^{2}K).

Roof: Plasterboard, 50 mm mineral fibre, protected vapour barrier of Swedish polyethylene, 200 mm mineral fibre between 50 x 200 mm rafters on 600 mm centres, 50 mm normal density expanded polystyrene sheathing. Clad with reconstructed stone tiles (U-value = 0.12 W/m^{2}K). The rafters span to a central ridge beam of built-up timber.

First floor: Concrete beam-and-block, with sand/cement screed.

Second floor: Timber.

Load-bearing cross walls: 100 mm dense concrete block, plastered both sides.

Windows: Of Swedish origin. 2+1-glazed with argon and one sputtered low-emissivity coating, in painted softwood frames (U-value = 1.35 W/m^{2}K). Fitted in the openings using timber cavity closers and sealed to the plaster using a strip of vapour barrier. Reconstructed stone external sills, concrete lintel in inner leaf and reconstructed stone lintel in outer leaf.

Rooflights: 3-glazed with argon and one sputtered low-emissivity coating, in aluminium-clad softwood frames (U-value = 1.7 W/m^{2}K).

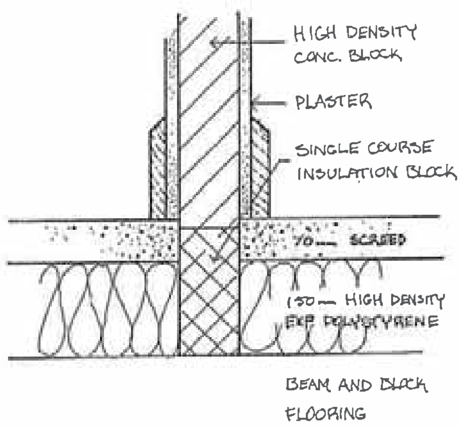
External doors: Metal-faced, insulated with 40 mm polyurethane foam (U-value = 0.65 W/m^{2}K).

Air leakage: Tight polyethylene vapour barrier throughout roof. Attempt to seal timber second floor to wall, using a polyethylene strip trapped below the plaster both top and bottom.

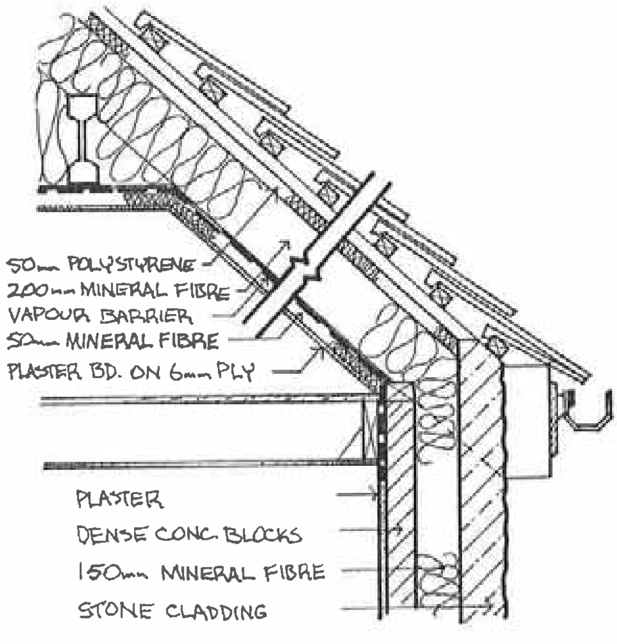
Initially, the air leakage was 3.6 ac/h at 50 Pa. The largest leaks were through a rooflight with missing weather stripping; around the threshold of two ground floor doors, where the strip of vapour barrier had not been sealed to the frame; through the junction between two soil pipes and the ground floor; through a first floor overhang; up the chimney, even with the woodstove doors closed; through the air supply to the woodstove; and at the junction of the timber second floor and the wall, where the detail drawn had not been built correctly.

Smaller leaks were noted around the opening light of one 2+1 window and between one rooflight and the roof structure. The second leak was attributed to a learning process; subsequent rooflights had been sealed correctly to the roof vapour barrier, and did not leak at all.

The leakage is likely to have fallen by undertaking remedial work, in particular, by blocking the five major leaks. However, this has not been measured.



Detail used to reduce thermal bridging at foot of internal wall



Roof detail

MASONRY

Lower Watts House

Given the bedroom wing above the garage, the first floor overhang, and the bathroom to the south-east, the house has a fairly complex shape, so the original 3.6 ac/h would be reasonably low by UK standards. However, the target had been 1 ac/h.

Services

Space and water heating: 20 kW gas-fired condensing boiler. Output adjusted to 7 kW, which is adequate for this house. Serves steel column radiators and a 210 litre mains-pressure hot water storage cylinder.

Five radiators were calculated to be adequate, but for aesthetic reasons eight were actually fitted, mostly on inside walls in the bathrooms, living room, study and hall. A house this size would normally have needed approximately 20 radiators, most of them located below the windows.

The controls comprise the boiler manufacturer's own system. This provides a weather-compensated circuit. The built-in software aims to 'learn' the dynamic thermal behaviour of the house in order to control the boiler in the most fuel-efficient manner and avoid overheating. Occasional secondary heating is provided by a woodstove and chimney, with an independent underfloor air supply.

Ventilation: Mechanical ventilation and heat recovery. Distributed in the UK, the system is based on a counterflow heat exchanger from the Netherlands and flexible circular ductwork.

The unit is located on the second floor. The system has three speeds – high for use when cooking or bathing, low for when the house is unoccupied, and normal. The total fanpower in normal mode is 85 W.

Cooking: Gas, lower cost-in-use and lower CO_2 emissions than the use of electric cooking.

Lighting: Energy efficient, wherever possible. Part of the kitchen, the garage and workshop are lit by electronically-ballasted 32 W fluorescent tubes, in luminaires with built-in specular reflectors. However, for aesthetic reasons, the fittings in the kitchen were later replaced by 18 W compact fluorescents in LED-100 downlighters.

Both these products were obtained from a firm that normally supplies lighting equipment to commercial offices. There were no suppliers serving the domestic market.

The rest of the house is lit by compact fluorescents. These were chosen to fit the few available shades on the market. A few cupboards and rarely-used rooms have incandescent lamps.

Electrical equipment: Most electrical appliances were brought from the owners' previous house. They will be replaced by more energy efficient ones as they wear out.

A Dutch energy efficient larder refrigerator was eventually sourced, but this took much trouble and effort. The conclusion was that none of the most energy efficient appliances sold in Denmark and Germany are readily-available on the UK market at reasonable cost.

Clothes are dried by hanging them loose on a rack in the main bathroom. No condensation has ever occurred.

Other environmentally beneficial features

The stone and concrete of which the house is built have a lower embodied energy than would clay brick or lightweight concrete block. The kitchen floor is clad with linoleum, not PVC. The kitchen furniture was made without the use of chipboard, to reduce formaldehyde emissions. The wooden second floor is finished with softwood boarding, rather than chipboard. Subject to aesthetic restrictions, some effort was also made to use water more efficiently. For example, the house has aerating sink and basin taps throughout and low-flow showerheads designed for mains-pressure systems, which were imported from the USA.

Total energy consumption

The estimated usage at design stage was about 70 kWh/m²yr. Over the first heating season with the house occupied, the measured usage was about 65 kWh/m²yr. See the table below.

Energy carrier	Purpose	Usage kWh/m²yr
Gas	Space/water heating and cooking	53
Electricity	Ventilation, lighting and appliances	12
TOTAL		65

Measured energy consumption in the period 1993-94

It is thought that the gas usage may drop slightly as the house fully dries out. The electricity usage may drop as more energy efficient electrical equipment is introduced.

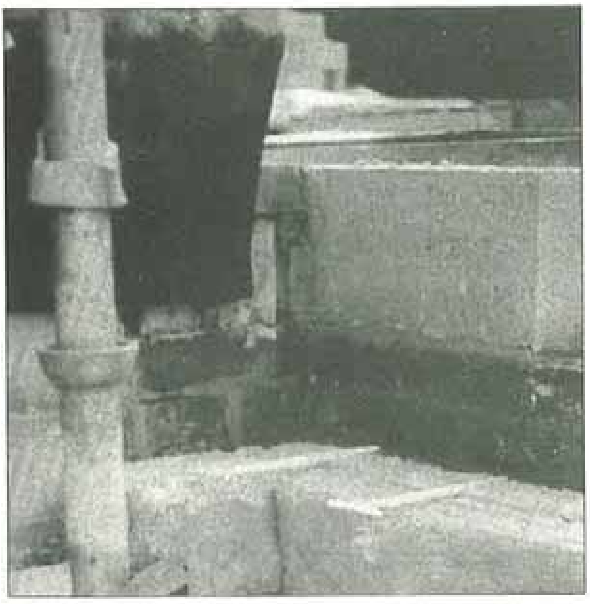
On the other hand, the owners choose to maintain an air temperature of around 19°C. This is pleasantly warm, in a house which has warm external surfaces, and few draughts. Gas consumption would rise if the householders chose to maintain an air temperature over 21°C, as was measured in some ultra-low-energy homes.

Cost

The cost was £550 per m². This was about the same as other custom-built houses in the area which were finished at the same time. The large savings on the number of radiators may have contributed to the nil overcost, although the heating system as a whole was quite expensive.

MASONRY

Lower Watts House



View of wall, showing the stone outer leaf, reconstituted stone jamb and cavity insulation

Experience/feedback

Drying out was a problem. Building work finished in January 1993, a time of year with low temperatures and little sunshine. An electric dehumidifier was used by the builders in the final stages of the work, but it could not fully cope with the moisture load. Because of security considerations, and wet weather in autumn 1992, the builders were reluctant to leave windows open overnight to disperse moisture; had this been possible, it would have helped. A significant amount of gas was burned to dry out the house after it was occupied.

If the ventilation system had been fully commissioned, it would have greatly helped to dispel the large amounts of moisture. As it was, condensation on all the glazing, and later on the rooflights alone, continued for several months.

With some exceptions, other aspects of the house construction worked well, and gave no real cause for concern. However, a few matters which arose at the design/construction stage, plus some which have arisen since the house has been in use, deserve comment.

At the second floor/wall junction, it was difficult to ensure correct workmanship and to achieve the intended airtight seal. A concrete second floor would have been easier.

The external door openings were also difficult to build. In practice, much debris collected in the cavity and had to be cleaned out. With the chosen roof arrangement, the wall plate had to be bolted down more securely than normal. This was, however, more a structural engineering than a building problem.

After the building had dried out, the rooflights remained prone to condensation at the edge of the sealed glazing unit, and on the timber kerb, in very cold weather. This thermal bridging was considered to be a significant defect. A different roof glazing system would be considered for use in future ultra-low-energy houses. By contrast, the 2+1 windows have proved almost immune from condensation in the most severe weather.

One of the air leaks has proved elusive. If it cannot be fixed, the heating system will have to be extended to the children's bedrooms, above the garage. This wing of the house effectively has five external surfaces. If such areas are to be heated by 'passive' heat transfer from the rest of the house, no major air leaks or thermal bridges can be accepted.

Accommodating ductwork in a house with solid upper floors must be an integral part of the design, from its inception. It was not hard to find routes for the ducts in this house, but with some floor plans there could have been serious problems. Mistakes were made in installing the ventilation system; the fitting instructions could have been made much clearer.

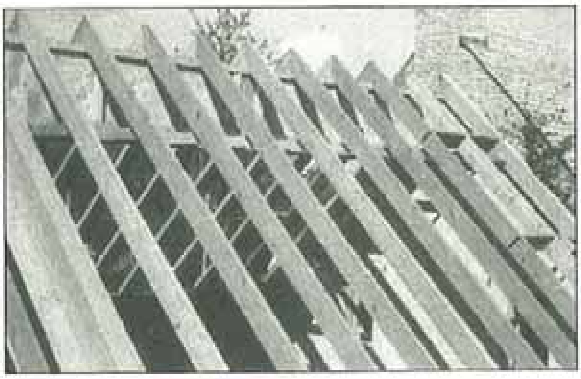
Noise at night from the ventilation system has been intrusive, especially in the master bedroom. So has noise from the boiler, whose pump and fan cut in whenever the external air temperature falls below 5°C – a quite unnecessary precaution in well insulated heavyweight houses, which can never freeze.

There has been condensation on the surface of the heat exchanger itself, and there are doubts that the system delivers the specified amount of fresh air in the main bedroom. Adjustments by the UK distributor have improved matters, but they have not yet eliminated the problem.

Commissioning of the space heating system controls was rather time-consuming, considering that this house has such a simple heating system. The controls worked very well after skilled personnel from the boiler manufacturer had made the adjustments. However, there is always a risk that the adjustments will not be made, and that such controls will waste more energy than they save. In smaller houses, a simpler approach would definitely be recommended.

Great care had been taken, wherever possible, to use gas for all services, to reduce both the house's energy costs and its CO_2 emissions. However, despite the house's electricity usage being only 12 kWh/m^{2}yr, the electricity bill slightly exceeds the gas bill, which surprised the owners.

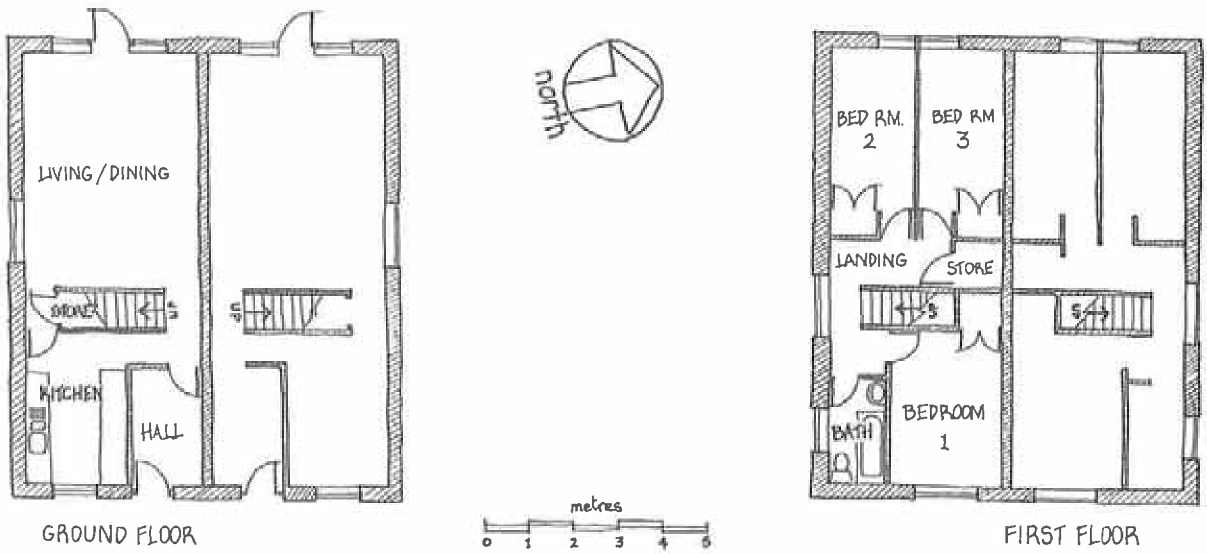
The bill is partly attributed to the children leaving all the lights on. The freezer and washing machine are old models, and are known to be relatively inefficient in their use of electricity. It is also thought that there is considerable 'parasitic' consumption by small appliances, eg the video, TV, fax, cooker clock, answerphone and computer power supply. Many of these devices draw from 2 to 10 W when they are plugged-in but are not in use.



View of roof under construction, showing rafters spanning to deep ridge beam

MASONRY WITH CAVITY INSULATION

45-47 Cresswell Road, Darnall, Sheffield (1992-93)



Client	North Sheffield Housing Association	**Architects**	Robert and Brenda Vale, Southwell
Quantity Surveyor	Gordon Hall, Grayson and Co	**Structural Engineer**	E J Allot and Associates, Sheffield

MASONRY

45-47 Cresswell Road

Nature of the buildings

Two 88 m² two-storey semi-detached houses. Three bedrooms, one bathroom. Much better-insulated than the 1995 UK Building Regulations require but built within a normal social housing budget.

Background

The principal motive behind the scheme was to improve the social conditions of the tenants, by reducing their out-of-pocket living expenses. Environmental factors were important, but they were definitely secondary to the financial aspects.

The houses in Cresswell Road also resemble a pair of semi-detached social houses which the architects designed for the same client in Industry Road, a year earlier, but are more conventional in appearance. These had also shown that low-cost, energy efficient social housing was quite feasible.

The Cresswell Road scheme followed several energy efficient medical centres which the architects had designed in the Sheffield area from the mid-1980s onwards. These were all modestly sized buildings, constructed in load-bearing masonry. The underlying construction details were based on experience with these earlier non-domestic schemes.

The architects' previous experience showed that if they produced a full set of very detailed drawings, the incidence of claims for cost overruns was much lower. This rule was carefully followed. As on previous projects, they invited tenders from a list of contractors who had a reputation for good quality work rather than rock-bottom prices.

Rear elevation

ELEVATION TO GARDEN

ELEVATION TO STREET

MASONRY

45-47 Cresswell Road

Fabric

Floor: Suspended reinforced in-situ concrete above 150 mm expanded polystyrene (U-value = 0.2 W/m²K). As is common in Sheffield, the site had abandoned cellars, which imposed extra foundation costs.

Walls: Plaster, 100 mm lightweight aerated concrete block, 150 mm built-in mineral fibre batts with plastic ties, 100 mm clay bricks (U-value = 0.21 W/m²K).

Roof: 12 mm plasterboard, 25 mm wiring space between 25 x 50 mm battens on 600 mm centres, 12 mm plywood, Swedish polyethylene vapour barrier, 400 mm cellulose fibre on attic floor (U-value = 0.08 W/m²K).

Internal partitions: Timber studwork; blockwork around stairs and porch. The first floor spans from external wall to party wall, and the roof from the front to the back of the houses.

First floors: Timber.

Windows: Of Swedish origin. 3-glazed with argon and one sputtered low-emissivity coating, in softwood frames (U-value = 1.5 W/m²K). They are fixed to plywood subframes in the openings, thereby minimising thermal bridging. Double concrete lintels and tile sills externally.

External doors: Softwood, insulated with 40 mm expanded polystyrene (U-value = 1.0 W/m²K).

Air leakage: Not known.

Services

Ventilation: Passive stack with humidity sensors.

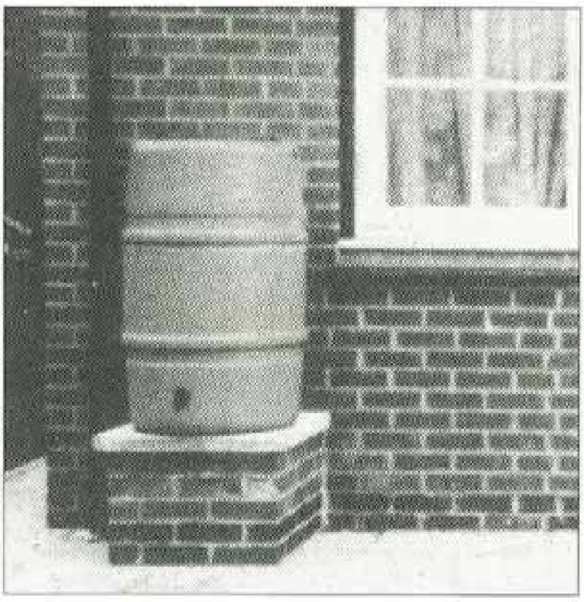
Space and water heating: Gas-fired condensing combination boiler, feeding radiators.

Lighting: Compact fluorescents. Energy efficient appliances could not be provided because of social housing rules.

Other environmentally beneficial measures

Rainwater is captured. Swedish water efficient WCs are used, with a 3.75 litre flush, and they reduce the annual water consumption of each house by about 40 m³. The external landscaping is designed to avoid run-off and minimise disturbance to the site's water balance.

An attempt was made to use materials which, in a UK context, have a relatively low embodied energy content. The designers also tried to use materials with a reduced environmental impact, both in a local and a global sense. For example, the downstairs floor covering is linoleum, not PVC; the first floor is clad with softwood, not chipboard; and the gutters are timber, not PVC. The kitchen cabinets are made from natural wood with metal handles rather than chipboard with plastic handles.



Rainwater collected for garden use

Energy consumption

The calculated energy need for space heating was 20 kWh/m²yr of low-temperature heat. This is 85% less than the figure for conventional new housing – calculated as about 115 kWh/m²yr. It assumes reasonably high internal temperatures by UK standards, not the very high temperatures observed in some ultra-low-energy homes. Monitoring in late winter 1993-94 by Pilkingtons, who manufactured much of the thermal insulation for the scheme, showed mean daily air temperatures of 21.2°C and 21.6°C in the two houses. It also suggested the energy usage in the table below; this is a mean for both houses.

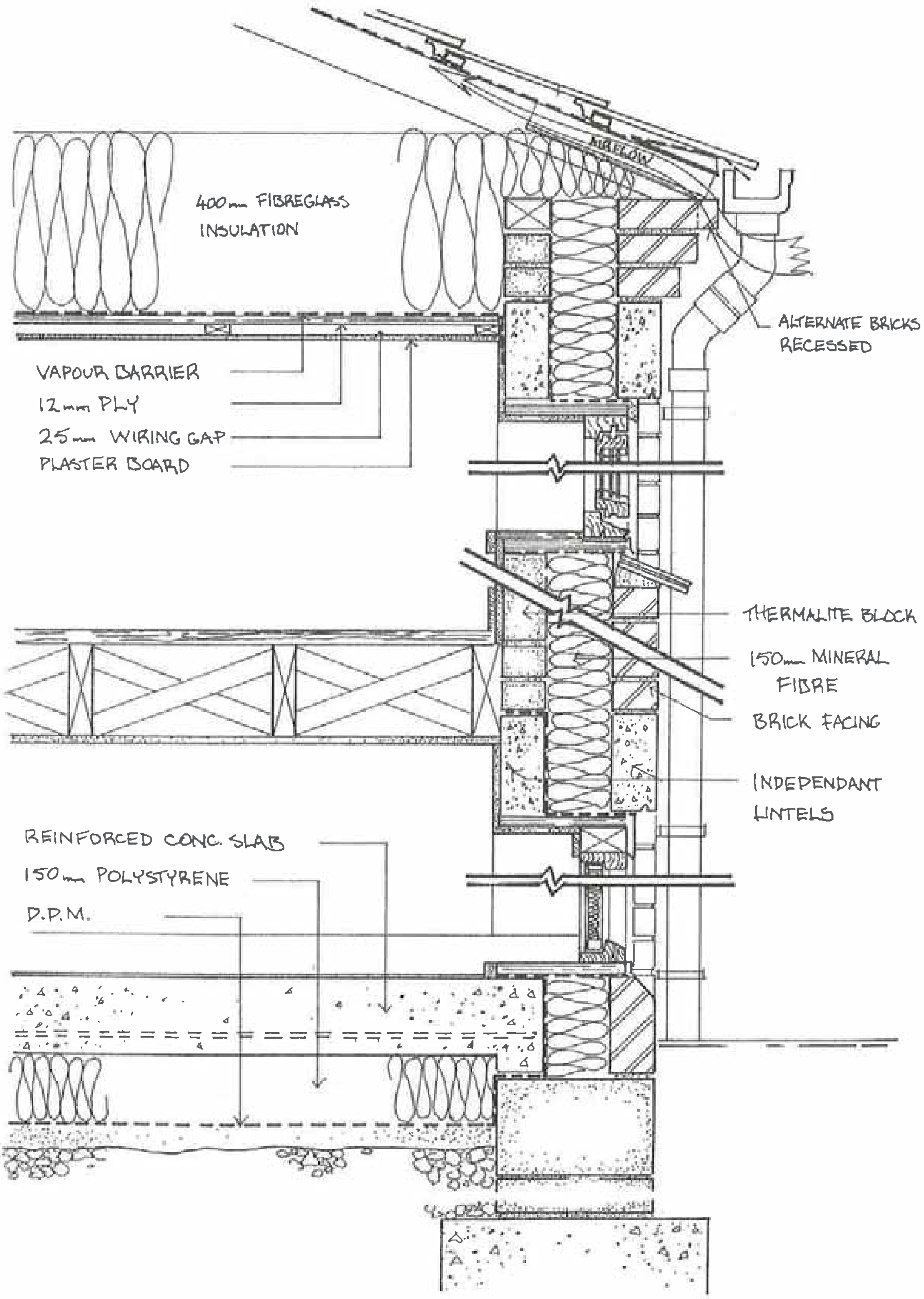
Energy carrier	Purpose	Usage kWh/m²yr
Gas	Space/water heating and cooking	108
Electricity	Lighting and appliances	26
TOTAL		134

Preliminary measurements of energy consumption in the year 1993-94

The electricity usage of both houses is similar, but one house appears to use 50% more gas than the other. At the time of writing the reason for this was unclear. As the houses would not have fully dried out, the gas consumption in particular should be treated as preliminary; it should fall significantly in subsequent years.

MASONRY

45-47 Cresswell Road



Cross-section through the houses, showing the floor, wall and roof insulation

MASONRY

45-47 Cresswell Road

Cost

The lowest tender received to build the scheme was £3000 per housing unit below the Housing Corporation's normal budget. The cost was about the same as normal housing developments completed by the Association during the recession.

Experience/feedback

The houses were occupied soon after the contractors moved out. This left little time for drying out. However, no complaints were received.

The Association's experience with drying out has been mixed. Some of their other developments have been built to moderately high standards and have been plagued with drying out problems; others have had no problem.

There has been a complaint from one tenant about the difficulty in drying clothes indoors in winter. There is no airing cupboard and no forced ventilation system either. There has been some condensation.

Comfort has been better than normal, even compared to the Association's normal new properties, which exceed Part L of the 1995 Building Regulations. A somewhat higher temperature has been maintained. Now that water is metered and tenants no longer pay a fixed charge, the potential bills for low-income families living in small homes have greatly increased. One tenant expressed appreciation that the houses are so economical on water.

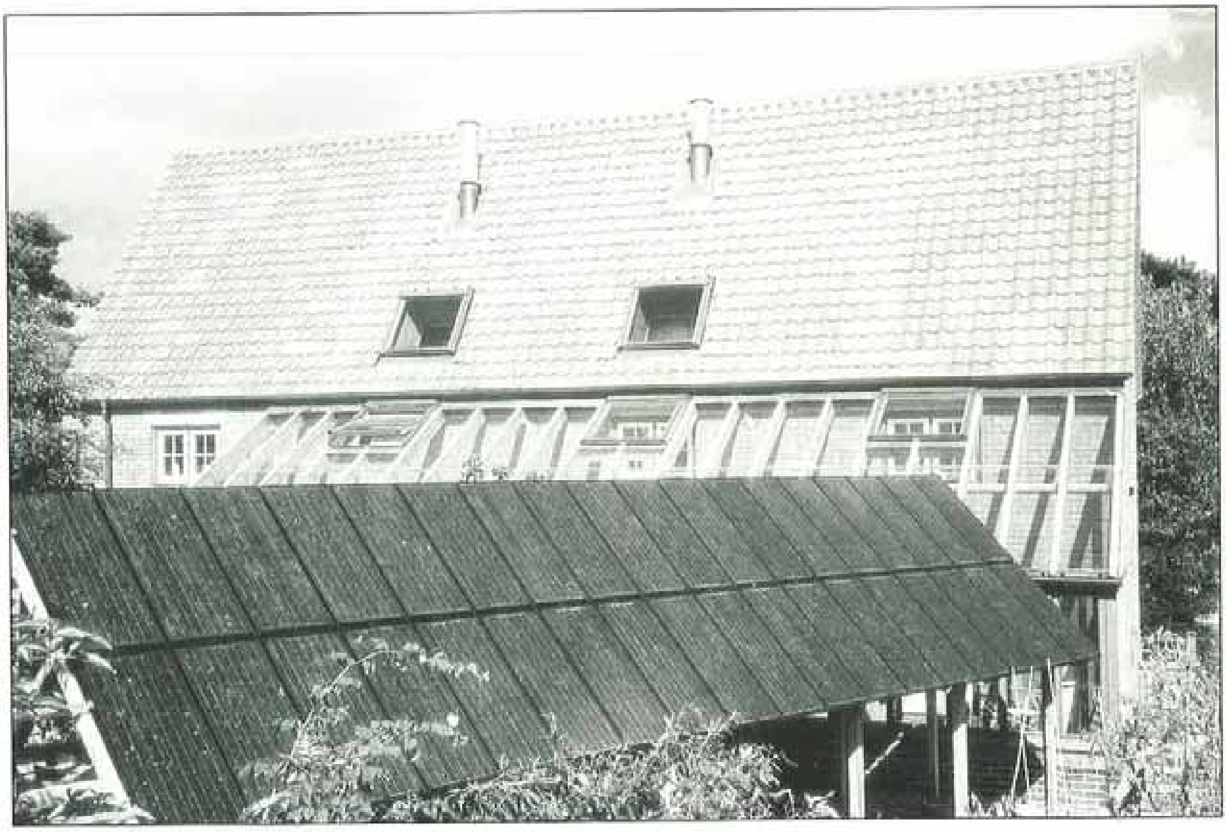
If the Association developed a similar scheme a second time, they would not do a great deal differently. They would mainly attempt to provide better facilities for drying clothes.

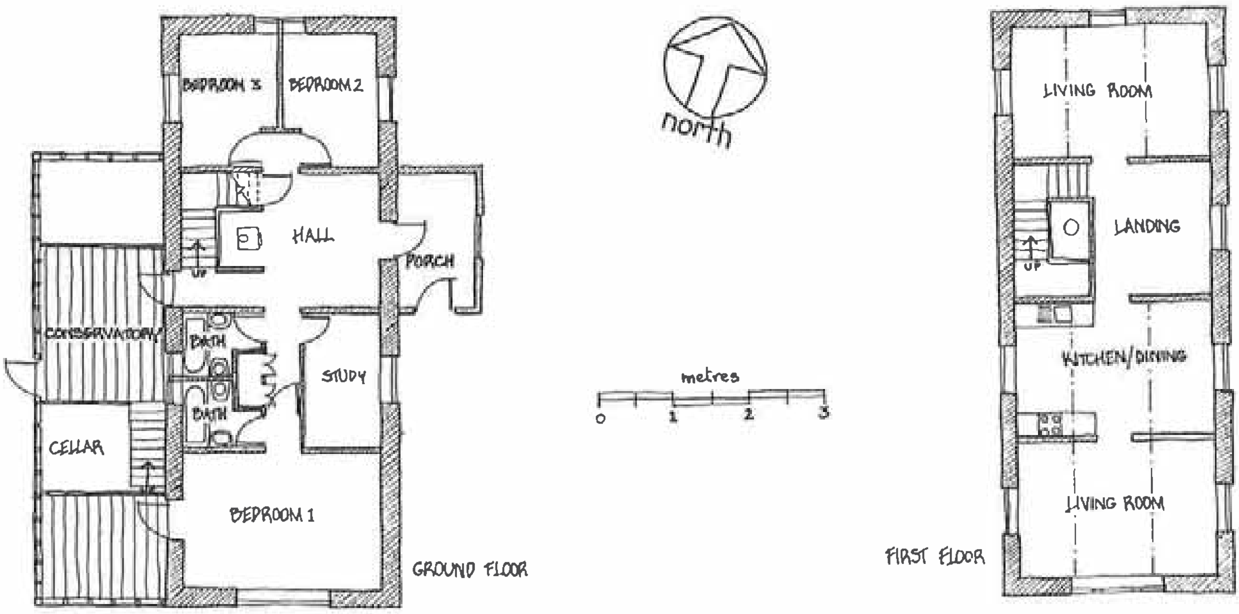
Adverse comments have been made about the high cost of replacing triple glazed, low-emissivity, argon-filled sealed units in the event of breakage. The authors suspect that 2+1 windows could overcome this objection; most breakages might then be confined to the single outer pane.

Finally, it is heartening to report the contractor's verdict. He said that overall, the scheme had been no more difficult to build than a normal one.

MASONRY WITH CAVITY INSULATION

The Autonomous Urban House, Southwell, Nottinghamshire (1993)





Owners and Architects Robert and Brenda Vale	
Builder Nick Martin, NSM Ltd, Southwell	**Structural Engineer** E J Allot and Associates, Sheffield

MASONRY

The Autonomous Urban House

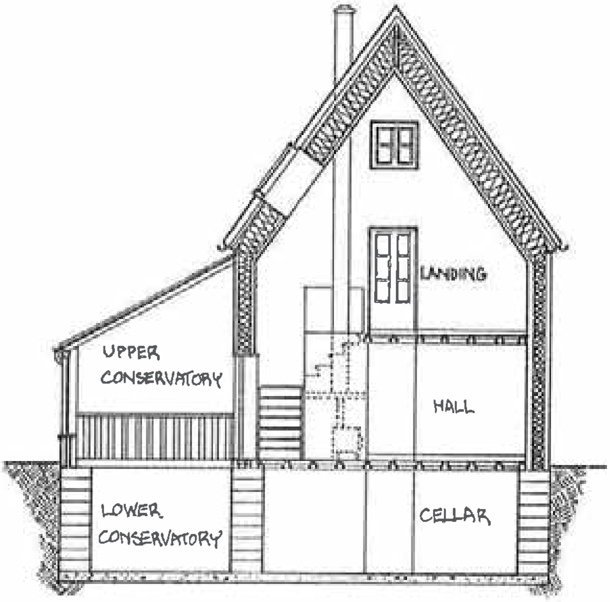
Nature of the building

2.5-storey detached house above unheated cellar. Four bedrooms, two bathrooms. The total floor areas of various spaces are approximately:

House 169 m² on three levels;
Porch 7 m²;
Cellar 66 m²;
Lower conservatory 28 m²;
Upper conservatory 20 m²;
totalling 290 m².

The site is located 300 m from a Norman minster, within the Southwell conservation area. The house ridge follows an almost north-south axis, in line with the existing built-up street. A two-storey conservatory is attached to the west-facing, garden side of the house, and there is a large porch on the street side. The cellar contains the rainwater store and various other services.

The bedrooms are sited on the ground floor, and the living rooms are on the first floor. This takes advantage of any stratification which occurs, and gives improved views. There is further space on a platform at second floor level, within the very steep pitched roof. This second floor platform also braces the gable walls.

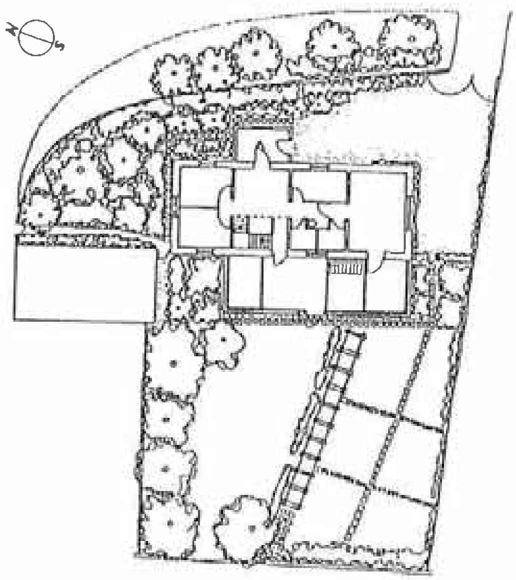


Cross-section through the house

Background

The aim was autonomy in all principal services. The house has no mains services except electricity and telephone. This drew upon the architects' 20 years of previous research in this field.

Consistent with the architectural approach, the photovoltaic (PV) system is placed on a pergola in the garden. The solar water heating system which was originally planned would have been sited high on the south gable end, not on the roof.



Site plan

MASONRY

The Autonomous Urban House

Fabric

Basement floor: 300 mm concrete raft foundation.

Basement walls: 2 x 100 mm lightweight aerated concrete blocks as permanent shuttering to in-situ reinforced concrete (U-value = 0.3 W/m^{2}K).

Ground floor: Concrete beam-and-block, with a sand/cement screed and with 50 mm cellulose fibre sprayed on the soffit (U-value = 0.6 W/m^{2}K).

External walls: Sand/cement plaster with finish coat, 100 mm dense concrete block, 250 mm built-in mineral fibre batts and plastic ties, 102 mm clay brick (U-value = 0.14 W/m^{2}K).

Internal load-bearing cross walls: Plaster, 150 mm dense concrete block, plaster.

Roof: 70 mm structural softwood decking, Swedish polyethylene vapour barrier, I-beam rafters with 500 mm cellulose fibre. Clad with clay pantiles (U-value = 0.07 W/m^{2}K).

Windows: Of Swedish origin. 3-glazed with krypton and two sputtered low-emissivity coatings, in wood frames (U-value = 1.15 W/m^{2}K).

Conservatory: Double glazed with argon and one pyrolytic low-emissivity coating, in softwood frames (U-value = 2.1/3.2 W/m^{2}K for vertical/sloping areas).

Rooflights: Glazing similar to conservatory, in aluminium-clad softwood frames (U-value = 3.3 W/m^{2}K). They were inherited from previous projects. If new roof glazing was being purchased, a higher specification would be chosen.

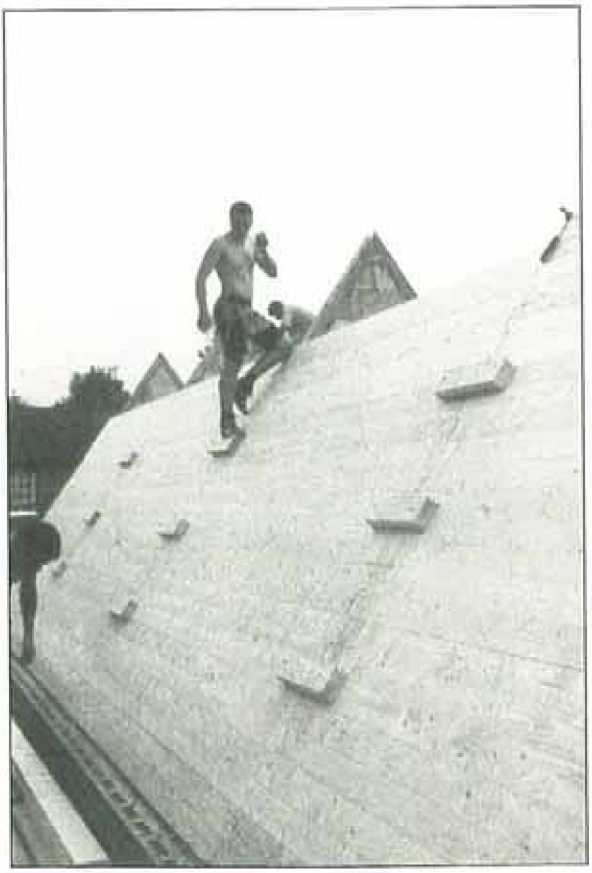
Air leakage: Not yet known. The architects noted the reports that air leakage in masonry buildings could be reduced by the use of heavyweight upper floors. This, and the desire for more thermal capacity to reduce temperature swings, is the reason why this house has suspended concrete floors.

Services

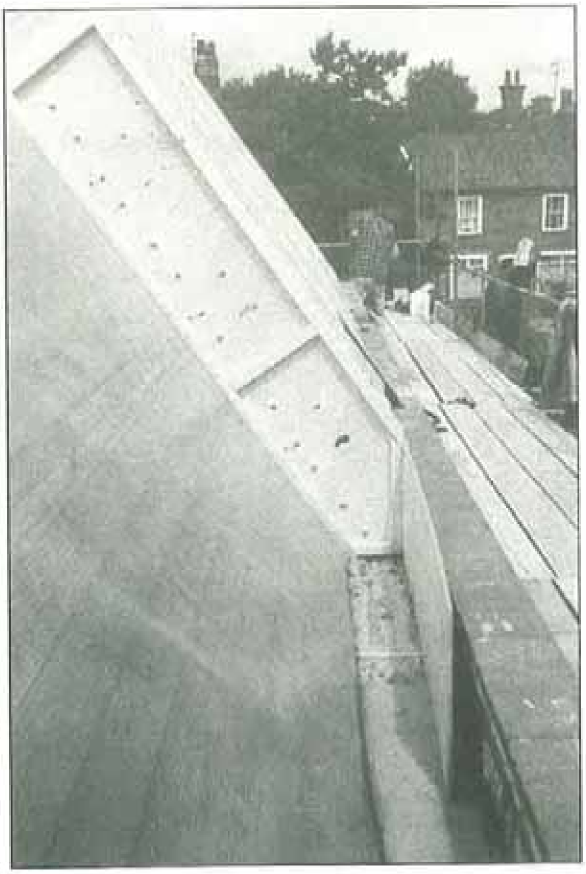
Ventilation: Through-the-wall mechanical ventilation and heat recovery units in 'wet' rooms, ie the kitchen and the two bathrooms. These units take preheated air from the conservatory.

The mechanical system does not extend to the other rooms in the house. The bedrooms have trickle vents in the window frames. The vents are opened at night.

Water heating: Heat pump using exhaust air from the composting toilet as the heat source. Estimated coefficient of performance (COP) 3.5. It is calculated that this will use about as much electricity as the original design, which was solar with electric resistance backup.



Roof decking between the load-bearing masonry cross walls



Vapour barrier laid over roof decking. I-beams provide space for 500 mm cellulose fibre

MASONRY

The Autonomous Urban House

Space heating: Passive solar with a 4 kW backup wood stove, and a ducted external air supply. It was calculated that the backup space heat input, in order to maintain a minimum air temperature of 18°C, would be 3 kWh/m²yr. In fact, the occupants operate the house at modest internal temperatures, and light a fire rarely or to provide a 'bright' point during overcast weather.

Electricity supply: 2.2 kW grid-connected PV system. A small backup battery in the cellar ensures continuity of water supply in the event of a power cut.

Water supply: Rainwater, collected from the roof via copper rainwater goods, runs by gravity to 30 m³ of storage tanks in the basement. These are scrap plastic fruit juice drums. It is pumped from there to a sand filter in the lower conservatory, from which it flows by gravity to a basement holding tank. For general use, it is pumped from here to a tank on the attic platform and flows by gravity to the taps without further treatment. For drinking and cooking purposes, it is delivered by gravity to a third tap at the sinks and basins, via a ceramic/carbon filter.

Sewage treatment: A Clivus Multrum M7 composting toilet. Vented by a 5 W fan operating at 12 V DC. Soakaway for grey water after passing through a grease trap. The details had to be approved by the National Rivers Authority.

Hardwood pergola to support the PV system

Other environmentally beneficial features

The selection of materials resulted from a careful assessment of their embodied energy, transport energy, and their implications for the internal environment and the health of the occupants. For example, the house foundations rest on demolition rubble from old brick buildings, rather than gravel. The concrete beams for the suspended floors were made locally, which reduces transport energy, and are reinforced with recycled steel. The concrete floor soffits are plastered, not lined with plasterboard. The clay bricks were made 60 km away, in a works fired by landfill gas. The roof was to have reclaimed clay pantiles, but new ones were used; the planning authority wanted to reserve the area's limited supply of reclaimed tiles for use on listed buildings.

Most floors are clad with clay tiles. A few loose rugs are provided, but the floors are free of carpets. These may pose health problems, not only because of the chemicals used in their manufacture, but because of the large quantities of dust and dirt which they collect. The kitchen furniture is made of beech and pine. Hence, it is chipboard- and formaldehyde-free.

Energy consumption

Before installation of the heat pump or PV system, the measured usage of electricity from the national grid was 3072 kWh/yr. It provided all services except space heating – hot water, cooking, ventilation, lighting, appliances, water supply and sewage disposal. During this period, the household size was either four or five people.

The installation of the heat pump is calculated to reduce electricity usage to 1450 kWh/yr. The output of the PV system from late July 1994 to early May 1995 was 1120 kWh, so the extrapolated production should reach a contribution of 1450 kWh/yr. This will give a net electricity input of zero from the national grid.

The house had almost dried out by the beginning of the 1994-95 heating season. In this mild winter, wood consumption amounted to 260 kg, or 1040 kWh. On the basis of a floor area of 169 m², the delivered wood consumption is therefore 6 kWh/m²yr, and the calculated heat output to the rooms is 4 kWh/m²yr.

Energy carrier	Purpose	Usage kWh/m²yr
Wood	Space heating	4
Electricity	Water heating, cooking, ventilation, lighting and appliances	18
TOTAL		22

Measured energy consumption

MASONRY

The Autonomous Urban House

Cost

The following building costs exclude land and fees. The share of the contract price for the house itself, plus the purchase/installation of the PV system, gives a cost of £680 per m^2.

However, the house is hard to consider in isolation; it is really part of a larger package, which includes the porch, cellar and conservatory. For instance, part of the cellar is used as a workshop, the conservatory is used for drying clothes, as a studio space and dining area, and both spaces contain components of the water supply and sewage treatment system.

The total contract sum for the project was just under £155 000. This gives a cost of some £540 per m^2, if one includes the areas of the conservatory, porch and cellar in the calculation, rising to £920/m^2 if one takes the house alone and excludes the areas of the porch, cellar and conservatory.

The cost per unit area is sensitive to which areas are included in the total floorspace. In a house with so many different types of space, there are clearly several possibilities.

Experience/feedback

As with some other tightly built houses of 'wet' construction, drying out was a great problem. During the period after moving in, water was seen to condense over parts of the glazing and the window plywood surrounds, and mould growth was observed at the edges of the rooflights. Condensation even occurred on the concrete floors at the corners of the house, where the floors meet the external walls, at points where air movement was restricted.

About 3000 kWh of wood was burnt in the first winter. The stove was useful, because its heat output reduced the internal relative humidity even at times when the air temperature was satisfactory. However, it was insufficient by itself. An electric dehumidifier was rented and used for two weeks.

The water store may have been over-designed for the family's actual water consumption. This has turned out to be 130 litres/day and not 200 litres/day as was assumed.

Generally, experience since occupation has been very positive. The drying out problem did not recur in the second winter and relatively little wood has been used for backup heating.

At all times, the air temperature in the living area has remained above 16°C. The lowest temperature was recorded during a one-week cold spell, in the drying out phase, over which the outside temperature was around 0°C and snow lay on the ground. Normally the living zone has stayed at 18-21°C and the temperature of the sleeping zone at 16-18°C.

The rooflights have given rise to noticeable downdraughts in severe weather, at least when the woodstove is running. The radiant cooling from the glass is not surprising, but the link with the woodstove operation is more puzzling. There is known to be a small air leakage path linked to the presence of the Clivus in the cellar; this has been sufficient to supply combustion air to the woodstove, and the duct built for this purpose has not been used.

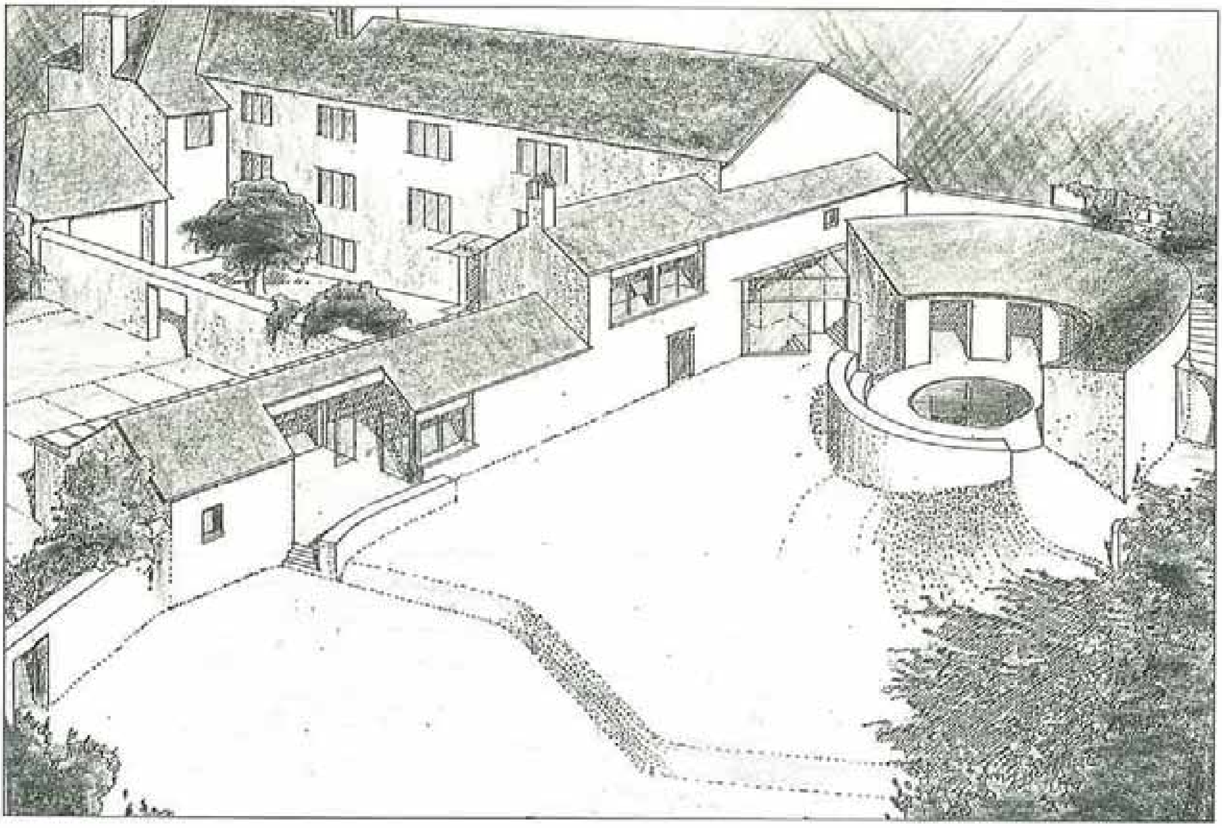
Since completion of the house in 1993, the soakaway in the garden has at times almost overflowed. This reflects two very wet winters and the local soil's low percolation rate. Modifications would be appropriate when such houses are next built in these ground conditions.

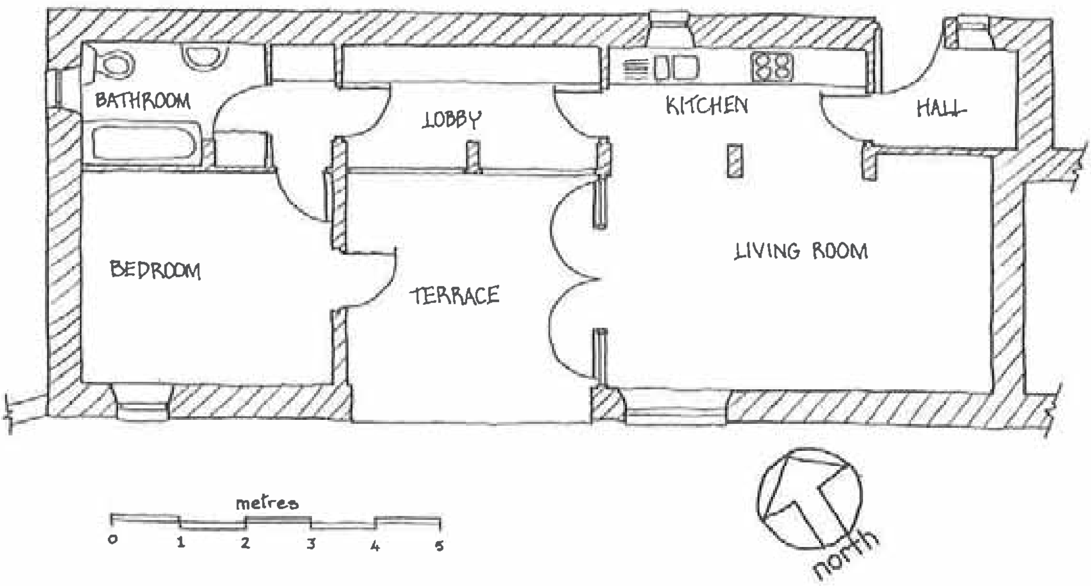
In most aspects, it appears that the standard of living has been on a par with normal UK households. There are differences, in particular the plumbing, but they do not seem to have made the house less convenient to live in.

The local planning authority has become extremely enthusiastic about the house. It has a stated policy of achieving another 100 by the year 2000. It is drafting building regulations for 'low-energy' homes (with energy efficiency standards similar to most of the schemes in this report) and 'autonomous' homes.

MASONRY WITH CAVITY INSULATION

Oasis Of Peace, Porthmadog, Gwynedd, Wales (1994)





Client	Catholic Centre for Healing in Marriage	**Architects**	David Lea, Ogoronwy, Penrhyndeudraeth, Gwynedd
Energy Consultant	Pat Borer, Pen y Bont Fawr Montgomeryshire	**Project Manager**	Richard Fox

MASONRY

Oasis Of Peace

Nature of the building

As the project title indicates, part of this scheme is non-residential in use. The project is an extension to a counselling centre.

The relevant part of the scheme is a 75 m^2 one-bedroom, one-bathroom house, for the use of the building's caretaker. The house is attached to the main centre and its rear facade faces 30 degrees south. The building is located on a town centre site, on the coast of north-west Wales.

Background

The clients were fully persuaded by the architect of the case for an energy efficient building and agreed with the architect's recommendations listed below.

The building uses high levels of insulation and thermal mass. In part, the architect wished to see how a high-mass building would perform in this climate, compared with previous timber-frame ones designed by his practice and with similar U-values.

The decision to use fully-filled cavities was taken late in the design process. It is not particularly exposed, but is still the most westerly site yet with masonry walls, a wide fully-filled cavity and built-in mineral fibre batts.

View from west during construction

MASONRY

Oasis Of Peace

Fabric

Floor: Softwood boarding, vapour barrier, 150 mm cellulose fibre between 195 mm joists on 400 mm centres, ventilated airspace, concrete ground cover (U-value = 0.18 W/m^{2}K).

Walls: 1:2:8 mix of cement-lime-sand plaster, 190 mm dense concrete block, 200 mm built-in mineral fibre batts with plastic ties, 100 mm clay brick, 30 mm external render of the same composition as the internal plaster (U-value = 0.17 W/m^{2}K). Outside to be limewashed.

Roof:

(1) Domed area with 50 x 75 mm joists on 400 mm centres, 350 mm cellulose fibre, rafters and purlins,

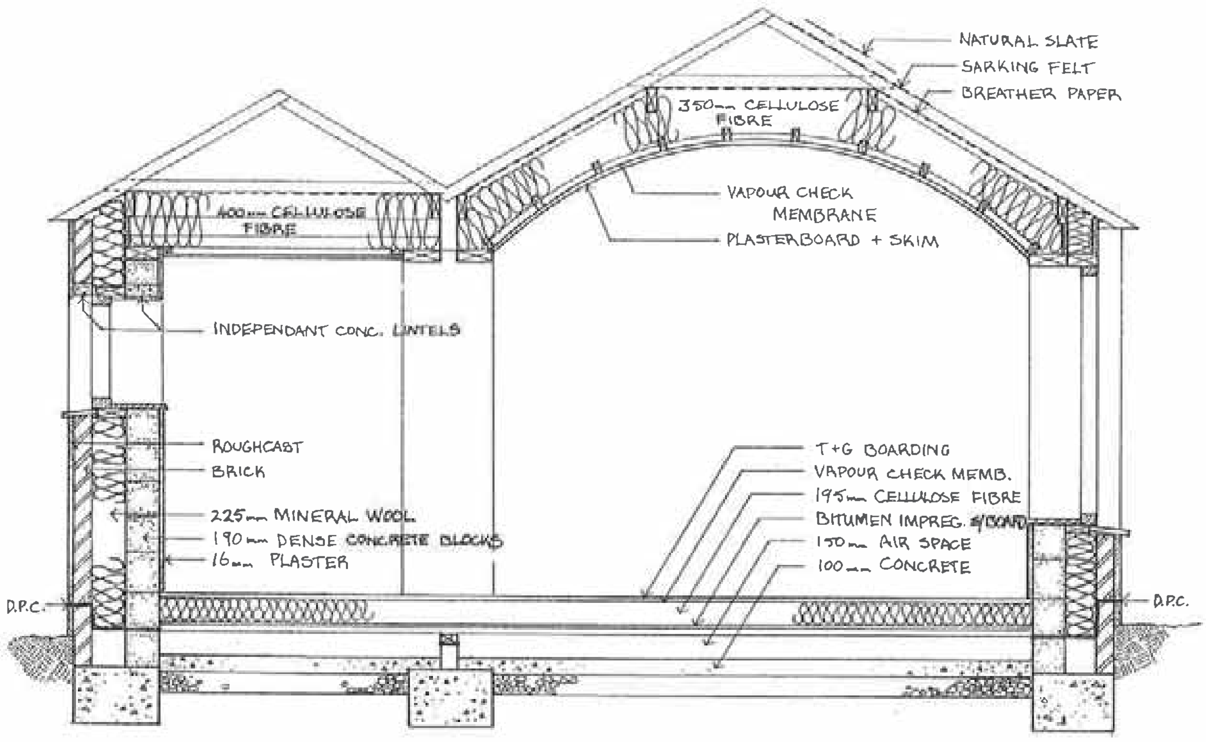
(2) Flat area with 400 mm cellulose fibre (U-value = 0.08 W/m^{2}K). All clad with natural slate.

Windows: Of Danish origin. Double glazed, air-filled, with one sputtered low-emissivity coating, in wood frames (U-value = 2.3 W/m^{2}K).

The windows are located in the plane of the thermal insulation. A softwood sub-frame is used to close the cavity, in order to reduce thermal bridging. Double concrete lintels. Slate external sills.

The fixed lights are direct-glazed into the sub-frame. This reduces the amount of timber and saves on costs.

Air leakage: Not yet known. There is an internal vapour barrier in the roof.



Cross-section through house

MASONRY

Oasis Of Peace

Services

Ventilation: Passive stack plus trickle ventilators in all window frames.

Space and water heating: Gas-fired condensing boiler and radiators.

Cost

The cost is expected to be £128 000 for the whole development of roughly 193 m^2. This is equivalent to £660/m^2.

However, the residential section of the scheme is almost certainly less expensive. The contract sum includes some rather expensive elements contained in the non-domestic section of the building, such as a pool with a curved wall of reinforced concrete, a large area of curved cavity masonry wall, which is featured in approximately half the building, and a curved slate roof. These features also caused considerable delays.

Experience/feedback

The initial standard of brickwork and rendering was unsatisfactory. After hiring different tradespeople, the quality of all work was excellent. The project has since proceeded in a much more cooperative spirit. The early problems did not affect the energy efficiency levels.

There is no conventional builder. The job carpenter is also acting as project manager, and he is responsible for managing the contract and for ordering materials. The architect has no doubt that this is the most effective way to reach high energy standards at reasonable cost.

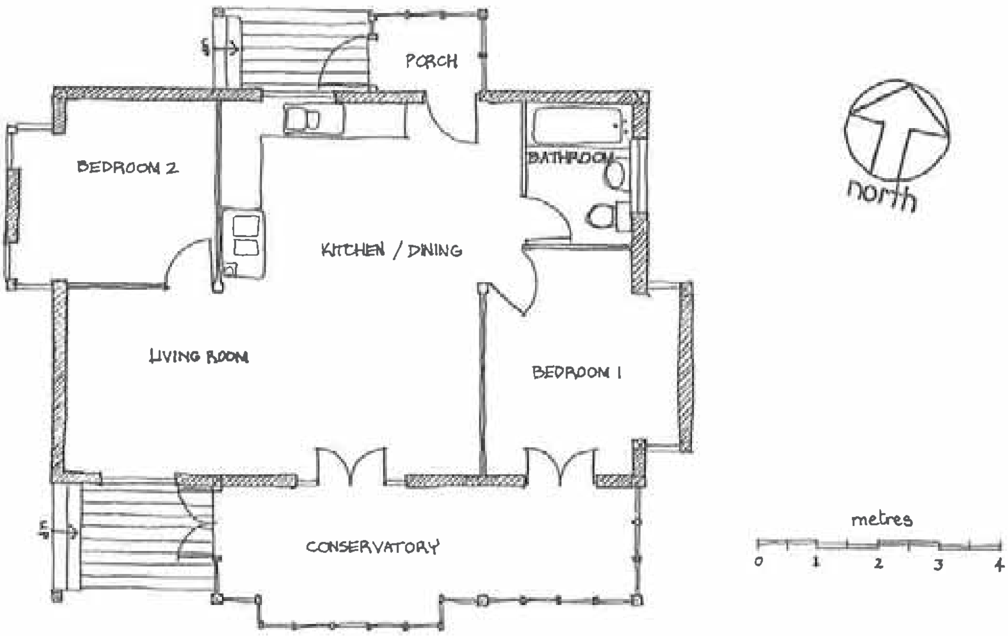
Many parts of the building were built in a different way from normal practice in the UK. To ensure that the correct procedure was followed, this implied extra supervision. For example, special care was needed to achieve a seal between the window frames and the plaster, and between the vapour barrier and the masonry walls. As on other buildings, the blown cellulose fibre sagged when it was held behind netting in vertical and sloping elements of the building, and an unscheduled extra delivery had to be made.

View of site, showing the house and the adjacent non-domestic building

Rear elevation, showing the double roof pitch

TIMBER-FRAME SITE-BUILT

Self-Build House, St Harmon, Radnorshire, Wales (1993-94)



Occupants	Ged and Maddie Lavelle	**Architect**	Pat Borer, Pen Y Bont Fawr Montgomeryshire

TIMBER-FRAME

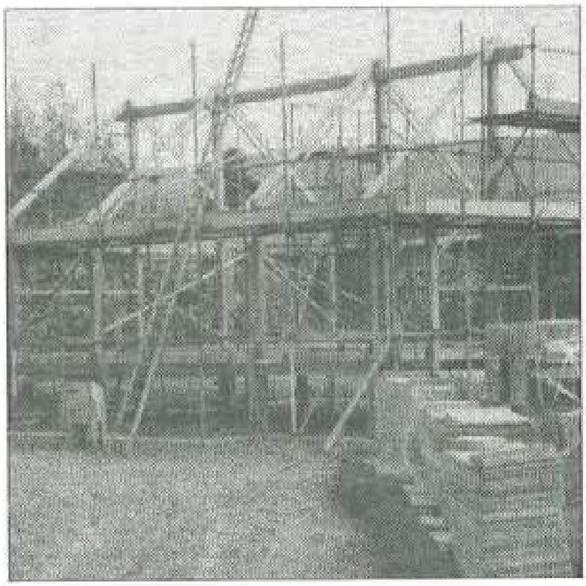
St Harmon

Nature of the building

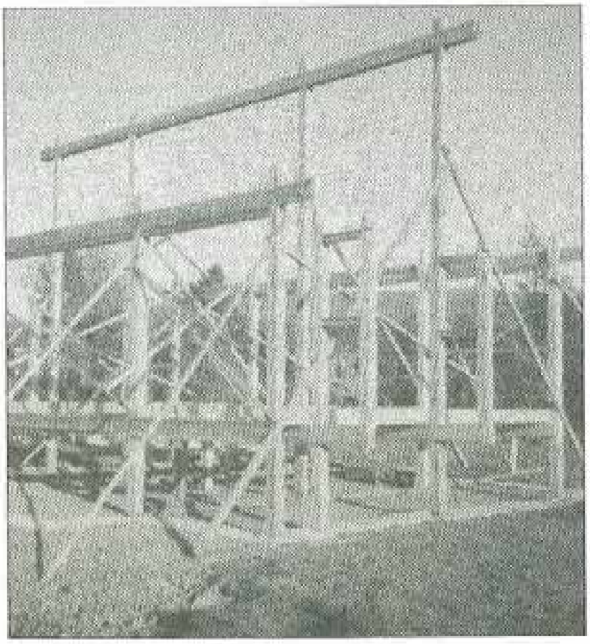
1.5-storey detached house. Three bedrooms, one bathroom. The ground floor area is 91 m², including one double-height space, and there is additional floorspace on the first floor. The resulting total is about 140 m².

This modified 'Segal Method' timber-frame post-and-beam house is located on a riverside plot in a mid-Wales village. There is a double-height kitchen and dining room in the centre of the house; otherwise, the layout is a conventional open-plan design. All timber is stained and left on view, giving an attractive internal appearance.

The south elevation is mostly covered by a single glazed sunspace. Much of the north wall is covered by a porch and store.



Rafters added to framing. Note the suspended rafters below



Frames on pad foundations

The National Rivers Authority perceived a risk of flooding on the site. The planners therefore required the house to be raised on posts 1.5 m above the ground. This gave a very deep crawlspace under the house.

Background

Initially, the occupants sought a rural building for conversion, with attached land. They soon concluded that this was a more expensive route to high energy efficiency standards than building a new house from scratch.

After visiting several energy efficient houses in Wales, they went on a self-build course at the Centre for Alternative Technology (CAT) at Machynlleth, read about some plots for sale in St Harmon, and bought the plot in October 1992.

The house was designed specifically for them by CAT's resident architect, and they built it from early 1993 onwards.

St. Harmon is located 300 m above sea level and has a mean annual air temperature of only 8°C, the same as Denmark. The area has frequent high winds and rain, so the demands placed on an energy efficient house are greater than they might be on a site in central England.

Rooflights provide good daylight and summertime ventilation. The cellulose fibre insulation with taped vapour control layer is expected to give good windtightness. Spaced studs and rafters and counter-joists in the floor result in greatly reduced thermal bridging, as well as being economical with timber.

The completed roof gives a dry working area

TIMBER-FRAME

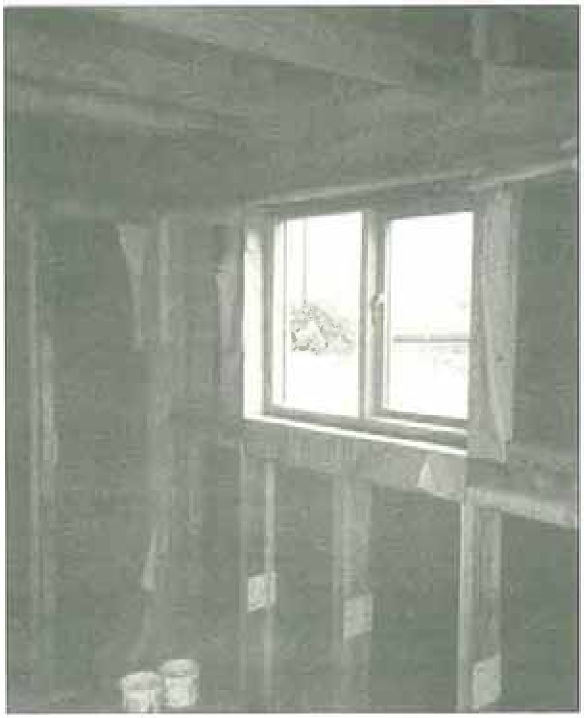
St Harmon

Fabric

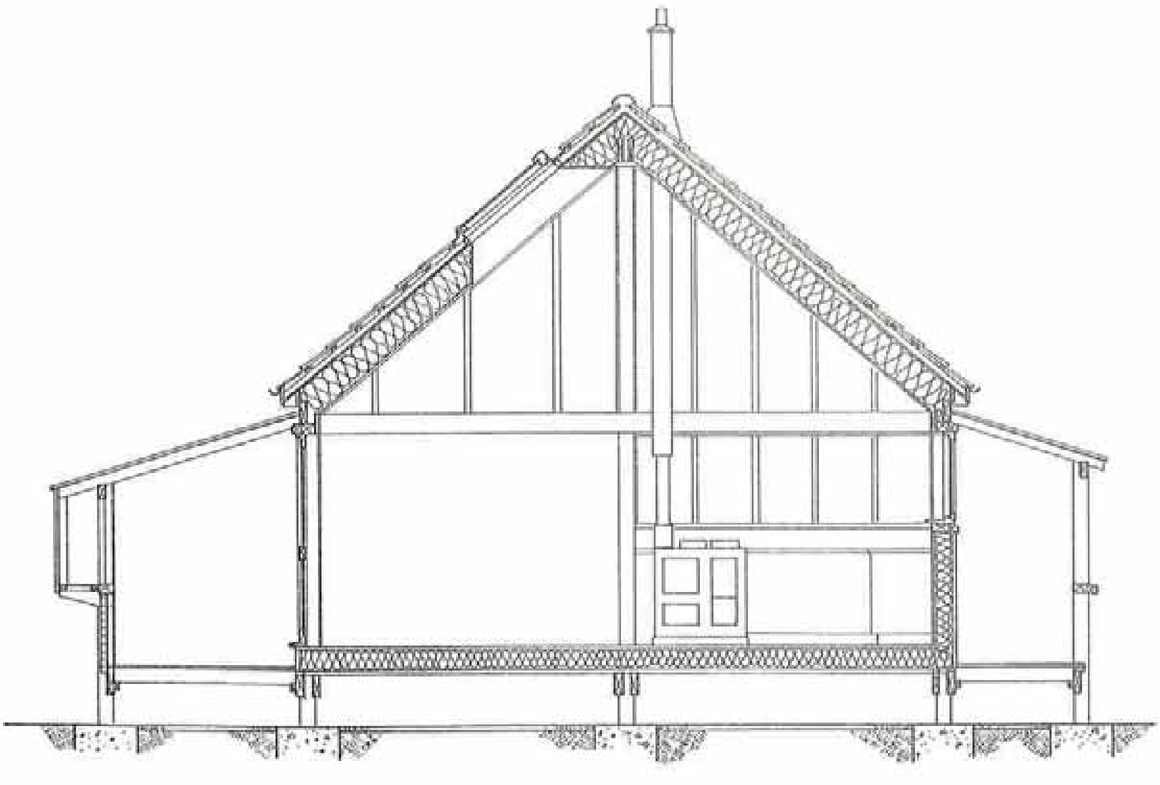
Floor: Suspended timber. Comprises 25 mm softwood boarding, 50 x 50 mm battens to provide a services void, 200 x 50 mm joists, with space between containing a total of 210 mm cellulose fibre, 12 mm bitumen-impregnated fibreboard (bif) on 25 x 25 mm timbers (U-value = 0.21 W/m^{2}K).

Walls: Wooden cover strips to retain plasterboard, 19 mm wiring void between 50 x 19 mm timbers, kraft paper vapour barrier, 150 mm cellulose fibre (cf) between 50 x 50 mm studs, 50 mm cf in 50 mm gap interrupted only by plywood spacers, 50 mm cf between 50 x 50 mm studs, 12 mm bif sheathing, woodwool slabs, sand/cement/lime render (U-value = 0.25 W/m^{2}K). Partly interrupted by a beam at first floor level.

Roof: Plasterboard, 19 mm wiring void between 50 x 19 mm timbers, kraft paper vapour barrier, double rafters comprising 50 x 50 mm rafters below, space and 150 x 50 mm rafters above, all filled with a total of 300 mm cellulose fibre, bif sheathing, treated counter-battens, spun polyolefin sarking, treated lath. Clad with concrete tiles (U-value = 0.13 W/m^{2}K).



Wall under construction, showing spaced studs



Cross-section through the house

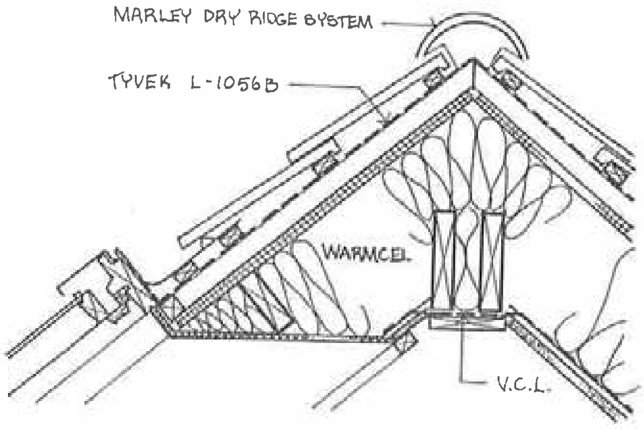
TIMBER-FRAME

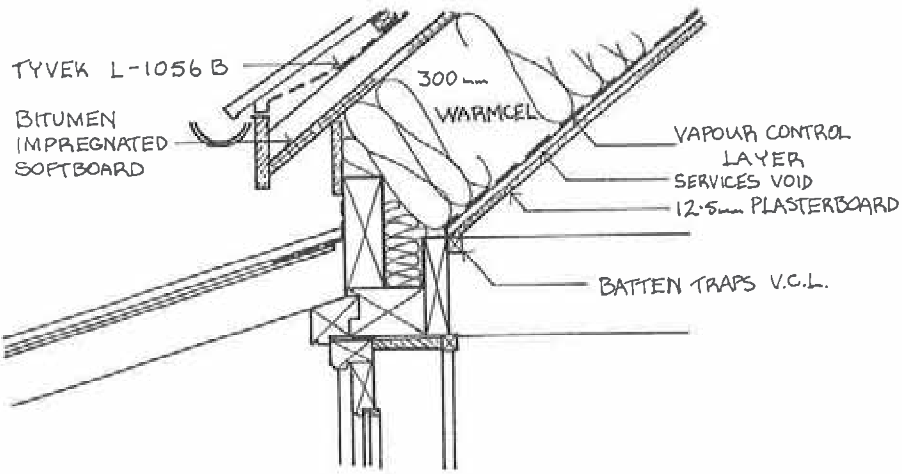
St Harmon

Windows: Of UK origin. A mixture of sealed double and triple glazing units in locally-made softwood windows and doors (U-value = 2.1-3.0 W/m^{2}K). The fixed lights are triple glazed, the opening lights are double glazed.

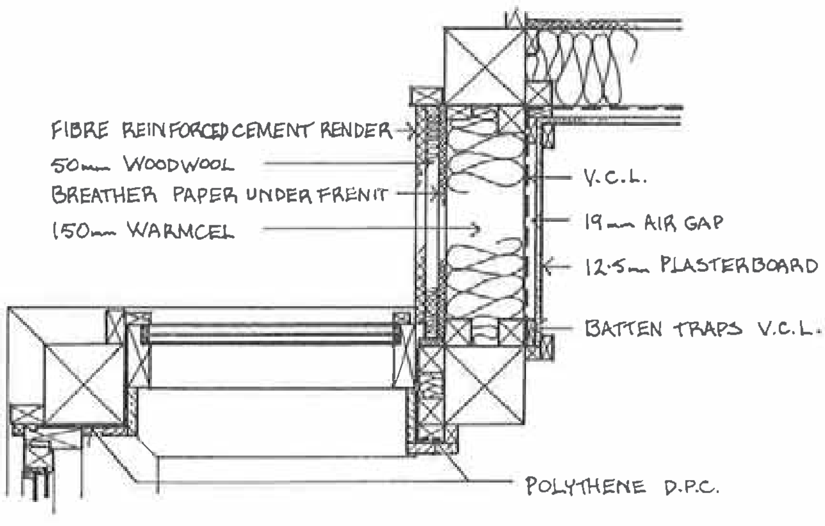
Rooflights: Double glazed with aluminium-clad softwood frames (U-value = 4.4 W/m^{2}K).

Greenhouse: Mostly single glazed, in wood frames. The opening areas are made from standard rooflights, and are double glazed.





Cross-section through roof



Plan at corner detail

TIMBER-FRAME

St Harmon

Services

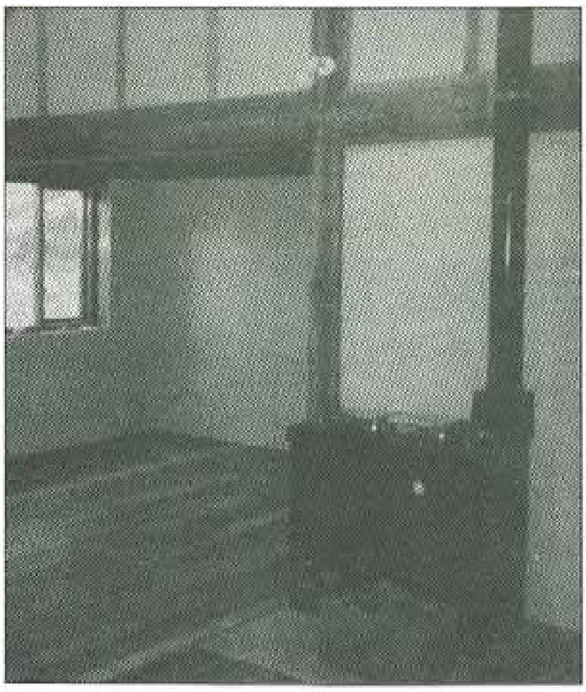
Space/water heating and winter cooking: Provided by a Rayburn stove burning wood on a renewable basis. A short air supply duct is provided through the suspended ground floor.

Being solid-fuelled, the system requires a 1.5 kW 'heat leak' radiator. The open-flued Rayburn provides some winter-time ventilation, as do extract fans. LPG hob for summer cooking. Summer water heating by electric resistance.

Lighting: Mostly compact fluorescent.

Electrical equipment: A normal level of energy efficiency for the UK. In most cases the owners required compact appliances, and they could not find energy efficient versions locally.

A typical delivery of the wood used for space and water heating and cooking



The Rayburn installed just before occupation

Energy consumption

The first year's wood usage was thought to equate to about 55 kWh/m²yr for heating and cooking. However, this was based on the estimated energy content of the first 6 tonnes of dry oak. Since then, softwood logs have been delivered regularly by a local farmer and burned after a few months storage. Consumption of this lower grade of timber has been about 15 tonnes per winter, at a cost of £180. Assuming a calorific value of 4 kWh/kg, this equates to 60 000 kWh of wood. If the conversion efficiency was 50%, which may be on the high side, the house is using low-temperature heat at a rate of 200 kWh/m²yr.

The mild weather overheating, and other experience with wood heat, suggests that the efficiency in use may be quite low. If one supposes a conversion efficiency of a little over 30%, then the amount of useful heat delivered to the rooms could approach 100 kWh/m²yr.

Environmentally beneficial measures

All the timber (structural, carcassing, joinery, windows and doors) is Welsh larch, converted and air-dried locally. No timber preservatives are used except in the roof. The use of pad foundations slightly reduced the amount of concrete.

External view, showing the woodwool slabs before rendering

Cost

The cost was about £35 000, which amounts to £250/m². This excludes the value of the owners' own labour.

The rendering and similarly skilled work was done by local craftsmen. Based on local experience, however, a masonry house of the same size could have been significantly cheaper.

TIMBER-FRAME

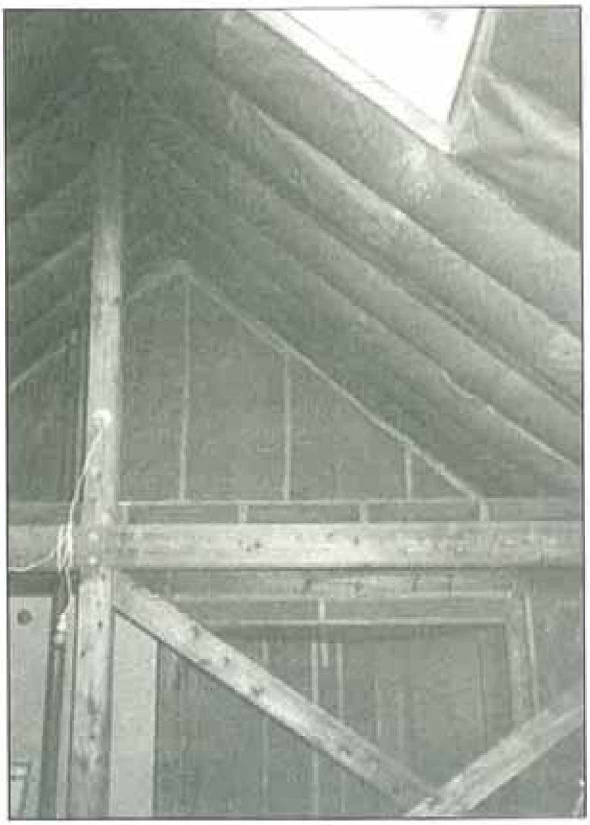
St Harmon

Experience/feedback

To install the roof insulation from the inside was very difficult. The netting sagged under the weight of 300 mm cellulose fibre, and the plasterboard had to be applied with great force. Given the amount of settlement, the supplier had to return to refill each cavity at the top.

Lifting the heavy rafters into place also took careful planning. Yet the outcome was that a reasonably energy efficient house was successfully built by two people who had no previous experience of building work.

The outside temperature fell to -14°C during construction, in winter 1993-94. Because of this, the owners moved out early from their caravan into the house. In hindsight, this was not recommended; living in the house greatly slowed down the finishing stages.



Roof vapour barrier bulging under the weight of cellulose fibre insulation

The drying out phase was trouble-free. Before cladding the walls with plasterboard, a few moist patches could be seen through the vapour barrier, in the cellulose fibre. These damp patches caused anxiety, but they disappeared after a few days.

The Rayburn-based heating system causes mild weather overheating, especially when a warm day follows a cold night. The heat leak radiator had to be enlarged to prevent boiling of the hot water cylinder.

The house is only fully closed-up in cold weather. On mild days, even in January and February, several windows are propped open. Because the system runs so much at part load, the chimney has needed more cleaning than expected.

The greenhouse rooflights leak in driving rain conditions. This is attributed to inadequate flashing at the junction with the greenhouse wall. Overall, the owners consider the standard of thermal comfort to be excellent. They wear much lighter clothing than in their previous houses and notice the difference in comfort when visiting friends and relatives.

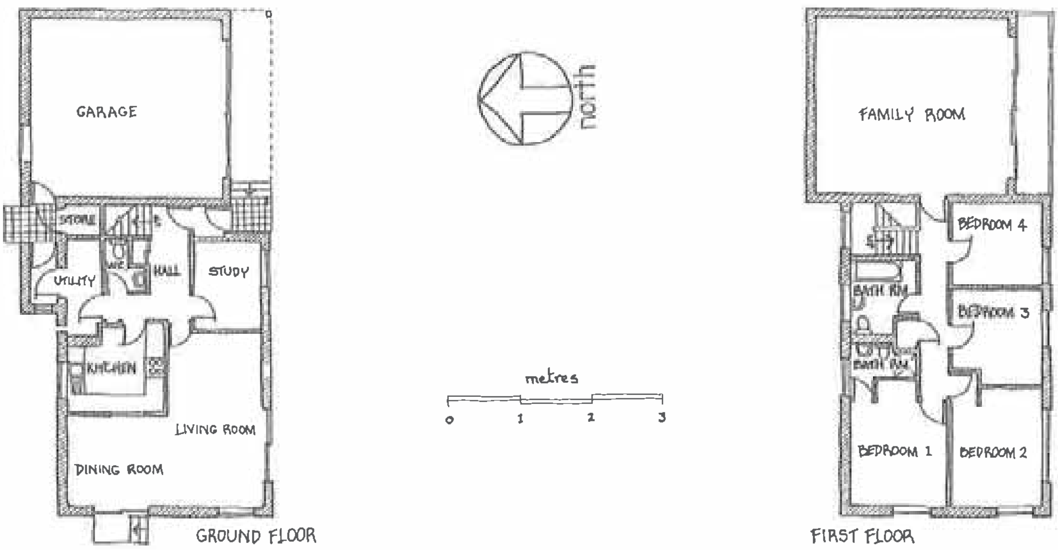
The house cools noticeably after they have been absent for a few days. However, it reheats extremely quickly.

The owners are now considering a solar water heating system for summer use. This would complement the Rayburn.

The kraft vapour barrier

TIMBER-FRAME SITE-BUILT

TTL Concept House, Futureworld, Milton Keynes (1994)



Architect	TRADA Technology Ltd, High Wycombe, Bucks	**Project Management**	Construction Surveying Associates Ltd, Milton Keynes
Timber Frame	Prestoplan Ltd, Preston, Lancs	**Developer/Builder**	Concept Construction Ltd, Towcester, Northants

TIMBER-FRAME

TTL Concept House

Nature of the building

176 m^2, two-storey detached house, with double garage. Four bedrooms, two bathrooms. The long axis lies east-west and the front of the house faces due south. All the living rooms face south or west, to take advantage of passive solar gains.

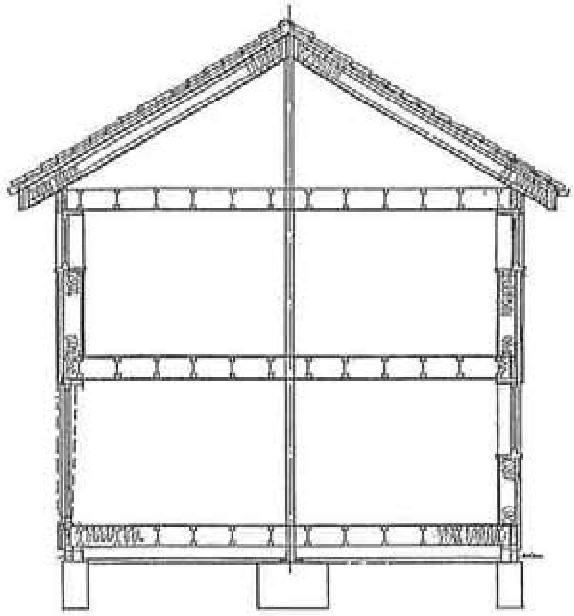
The house is factory-built to a lesser degree than some new Scandinavian timber-frame homes. Even so, much more work was done off-site than for any of the other three timber-frame houses.

The I-beams are used in wall, floor and roof panels to provide long spans. This eliminates the need for internal load-bearing walls. They are structural composites, of North American origin, and consist of laminated veneer timber flanges combined with plywood webs.

North American material called Parallam is used. This is made from resin-bonded wood fibres. It can be extruded into long beams of any length and in a range of cross-sections.

Background

This is a prototype house using prefabricated I-beams in factory-produced panels to produce a flexible, highly insulated house. The project demonstrates a large number of new technologies. In the sponsors' view, they all indicate the direction in which UK timber-frame house construction will move in the future.



Cross-section through the house.

View of the rear elevation

TIMBER-FRAME

TTL Concept House

Fabric

Floor: Suspended floor panels delivered complete with plywood deck, 300 mm insulation and impregnated softboard layer on underside (U-value = 0.11 W/m^{2}K).

Walls: The roof and walls have no polyethylene vapour barrier. Cellulose-reinforced gypsumboard with two coats of sealer, acting as a vapour control layer, 240 mm mineral fibre between I-beams on 600 mm centres, bitumen-impregnated softboard sheathing. Externally clad by a mixture of render on ground floor and vertical boarding of impregnated softwood on first floor (U-value = 0.15 W/m^{2}K).

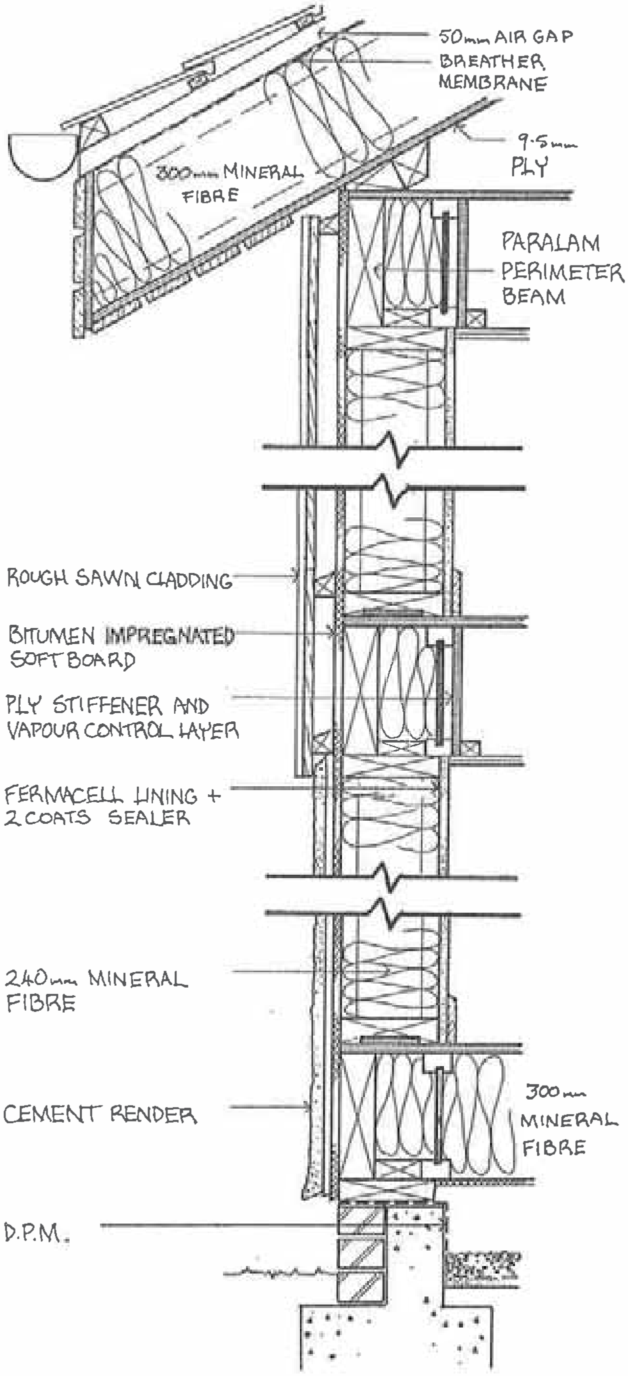
On the two facades where the joists run parallel to the wall, the walls are insulated at intermediate floor level. They are not insulated on the other two facades, where the joists span at right angles to the wall.

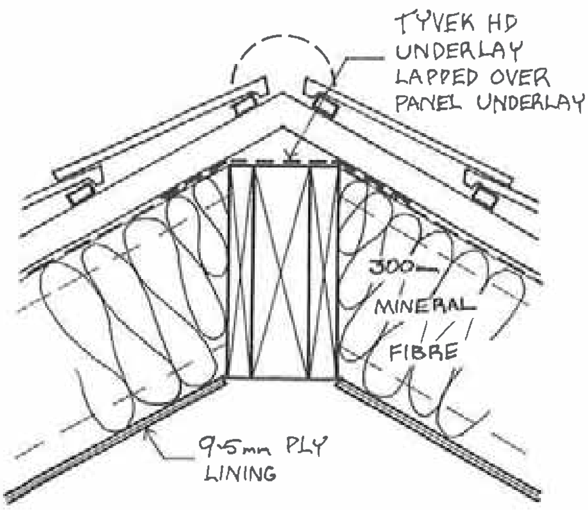
Roof: The roof insulation follows the slope. Faced with plywood internally, 300 mm mineral fibre between deep I-beams on 600 mm centres, a spun polyolefin breather membrane, 50 mm air space above the insulation, clad with concrete pantiles (U-value = 0.12 W/m^{2}K).

Windows: Of UK origin. Double glazed with 20 mm air gap, in wood frames, and of projecting reversible design (U-value = 2.7 W/m^{2}K).

Patio doors: Glazed as windows. Of slide-and-tilt design, which should give both good security and good airtightness.

Air leakage: Not known. The problems described below suggest that it may be quite high.





Section through wall

Ridge detail

TIMBER-FRAME

TTL Concept House

Services

Space heating: Gas-fired high efficiency but non-condensing boiler, feeding a radiator system with TRVs. All major rooms have a radiator, and all the heat emitters are sited on internal walls.

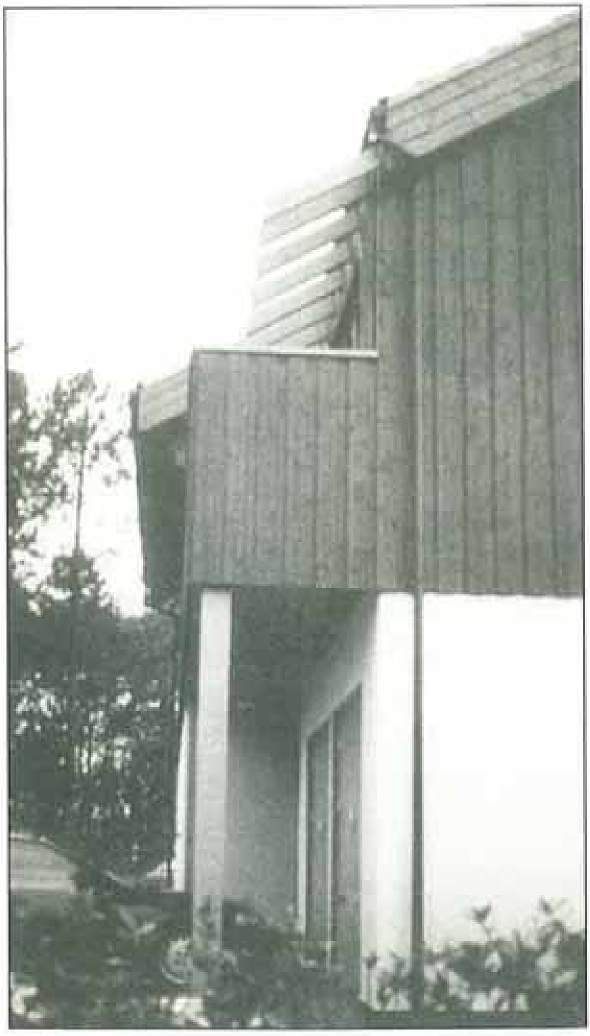
Water heating: Mains-pressure system, served by the same gas boiler and with a normal storage cylinder.

Ventilation: Passive stack ventilation with humidity-controlled exhaust and supply air grilles.

Lighting: All the ceiling and wall fixtures are designed to take compact fluorescent lamps. External lighting is by 25 W low-pressure sodium lamps, which are left on for up to 10 hours/night.

Energy consumption

Meter readings are available for the period since the occupants moved-in, a few months after Futureworld closed. They indicate a gas bill of approximately £30/month and an electricity bill of the same magnitude.



Side elevation, showing balcony above garage

The gas bill corresponds to delivered energy consumption of 130 kWh/m^{2}yr. Although it was for the colder months, the winter was very mild. On balance, even if future winters revert to 'normal' temperatures, it is thought that the gas consumption should decline as the air leaks described below are fixed.

The electricity bill corresponds to about 23 kWh/m^{2}yr, and is unexpectedly high. The only major new appliance compared to those in the owners' previous house, which had lower bills, is a dishwasher. There are no incandescent lamps in the house, nor are there any devices with significant electric heaters. Investigations by the owners, who have some knowledge of the field, continue.

Cost

The cost is not known precisely. The house was specially-built for the exhibition. All the timber-based products and materials were donated to the project.

Experience/feedback

The house was erected on a very short timescale. With hardly any 'wet' trades used, there was no drying out problem. Nor has there been any condensation or lingering odours.

In autumn 1994, after moving in, the occupants found that several features of the house did not appear to be very well-sealed. The roof had major leaks at the gable end. These were attributed to a lack of understanding by the workforce; the house had a warm roof and needed no ventilation below the rafters. Even when these leaks were fixed, there appeared to be considerable leakage, with the result that the house cooled down quickly after a change in the weather.

Numerous draughts through service penetrations in the floor were observed. It was determined that not only had these openings been made unnecessarily large, but they had not been correctly sealed. The electrical sockets on the external walls leak. Admittedly, this is a common problem in timber-frame buildings unless special measures are taken. The draughts are slowly being fixed by the owners.

There were problems with the central heating system. A report was commissioned from a consulting engineer. It was determined that among other mistakes, the piping had been connected wrongly. This was the root cause of the whole system repeatedly boiling and venting into the header tank. The necessary corrections now appear to have been made.

The house has noticeably small radiators. Experience has shown that the radiator in the first floor family room is under-sized. Its output is incapable of maintaining an internal air temperature of 20°C when the outside temperature is -1°C. In more normal winters, when the outside air temperature quite often falls below -5°C, there would be real problems.

The supply temperature, and the temperature difference between supply and return, are both correct. The apparent cause is either the use of too small a heat emitter and/or poor workmanship, which led to extra air leakage. Despite this list of problems, the occupiers now seem to be confident that matters will be resolved. They notice a major improvement in comfort as each air leak is removed.

TIMBER-FRAME

TTL Concept House

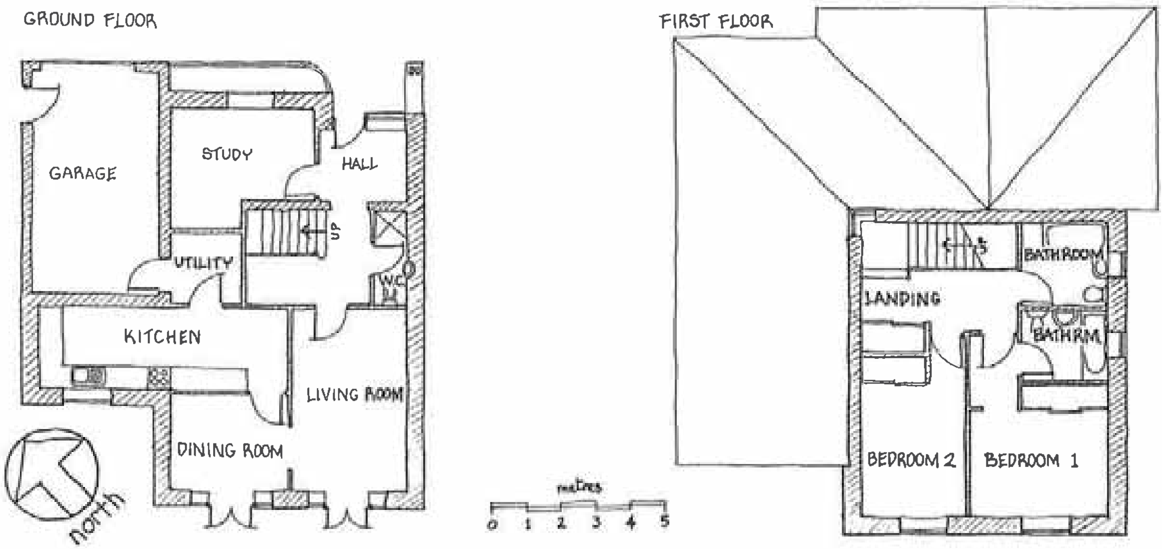
It appears that if more care had been taken over all aspects, and if the Futureworld Exhibition had been designed and built over a longer time-scale, there would be much fewer defects. In particular, it is worth noting that the designers of this house were not responsible for supervising construction, or for the design of the services and the internal layout. In contrast, on the Lifestyle 2000 House, built at Energy World eight years earlier, and which achieved a good airtightness, the designers were responsible for supervision.

The bulk of these problems seem to be attributable to the standard of UK building workmanship in general, not energy efficiency per se. However, they indicate how unfamiliar the concept of airtightness remains on many UK sites.

South elevation, showing position of optional conservatory

TIMBER-FRAME SITE-BUILT

'Winslow' Two-Bedroom House, Futureworld, Milton Keynes (1994)



Client	Electricity Association Ltd, London	**Architect**	The Charter Partnership, Bedford
Design and Build Developer	Admiral Homes Ltd, Luton, Beds	**Timber Frame Designer**	Frameform Ltd, Wolverhampton
Timber Frame Supplier	Potton Timber Ltd, Potton, Beds		

TIMBER-FRAME

'Winslow' House

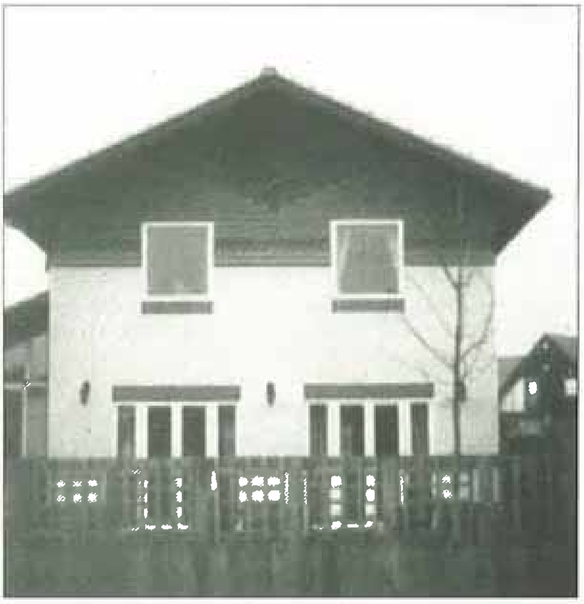
Nature of the building

121 m^2, two-storey detached house, with single garage. Two bedrooms, two bathrooms; in addition, a downstairs room near the entrance is readily usable as a study or a third bedroom. The living rooms at the back of the house face approximately south-west, taking good advantage of passive solar gains.

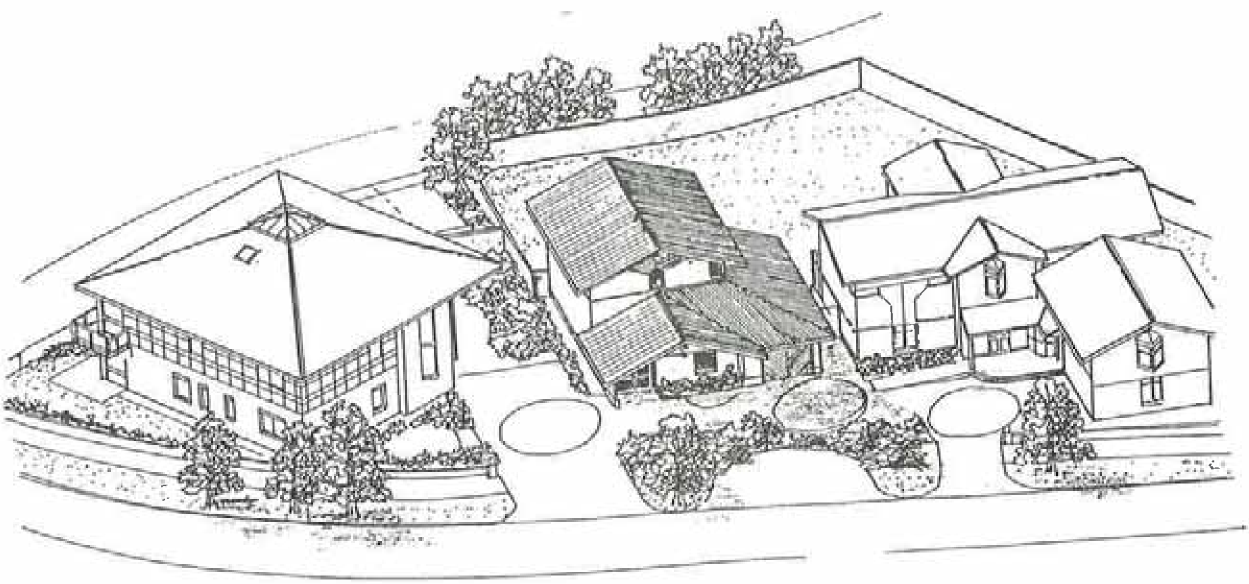
Background

This is one of the UK's most highly insulated timber-frame houses to date. It would probably comply with the insulation requirements in Sweden's 1989 Building Regulations, which are extremely demanding.

It was intended to be the lowest energy house at the Futureworld Exhibition. To a significant extent, cost was subordinated to energy efficiency. Innovative approaches were not ruled out, even though experimental techniques usually cost much more when they are done for the first time, especially under extreme time pressure, than when the same item enters widespread use.



View of rear elevation



View of the Winslow house, between the flats and the four-bedroom house at Futureworld

TIMBER-FRAME

'Winslow' House

Fabric

Floor: 22 mm chipboard, 100 mm mineral fibre between 100 mm timber joists, above a concrete suspended beam-and-block floor (U-value = 0.3 W/m^{2}K).

Walls: Of double-stud construction, with a total wall thickness of 460 mm. 12 mm plasterboard, 50 mm service cavity for wiring and/or pipework, polyethylene vapour barrier, 90 x 38 mm studs on 600 mm centres, 50 mm gap, 90 x 38 mm load-bearing studs on 600 mm centres, all filled with a total of 250 mm mineral fibre compressed to 235 mm, plywood sheathing, breather membrane, 50 mm clear cavity, tile hanging or rendered blockwork (U-value = 0.15 W/m^{2}K). With the double wall construction, it is possible to have a continuous layer of insulation at first floor level; this is usually a weak point in timber-frame buildings.

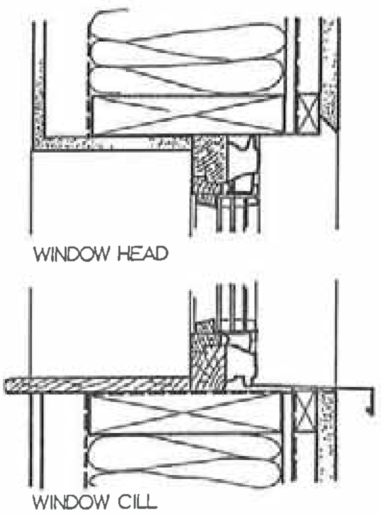
Roof: 12 mm plasterboard, vapour barrier, 300 mm mineral fibre on the attic floor, loftspace. Clad with concrete tiles at a low pitch (U-value = 0.12 W/m^{2}K). A special eaves detail ensures that the full depth of insulation continues over the junction of the roof with the wall. The bottom chord of the trusses is 200 mm deep; cross-battening with 100 mm joists can provide a walkway without compressing the insulation. The loft hatch is insulated and weatherstripped.

Windows: 3-glazed with argon, in wood/aluminium frames (U-value = 2.0 W/m^{2}K). Of Swedish origin. These are composite frames rather than aluminium-clad wood frames. They have no low-emissivity coating, which is unusual for argon-filled units.

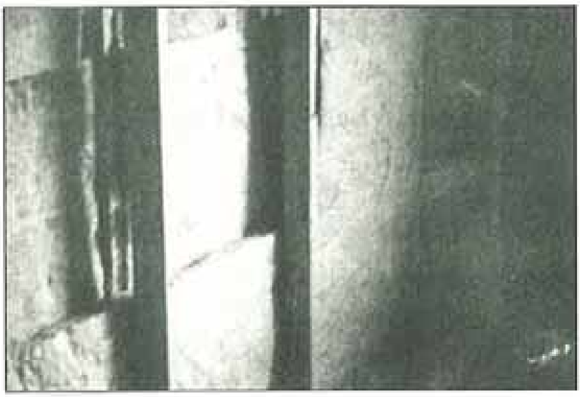
External doors: Insulated, weatherstripped, metal-clad, same maker as windows (U-value = 0.65 W/m^{2}K).

Air leakage: Initially, the measured air leakage was 2.16 ac/h at 50 Pa. Leaks were noted through the plasterboard above the kitchen cupboard/cooker hood, behind the vanity unit in the en-suite bathroom, around soil and waste pipes, around the electrical service entry, around a socket and some light fittings, around the loft hatch, around pipes which entered the airing cupboard, around the garage door, plus minor amounts around the front door and some electrical sockets.

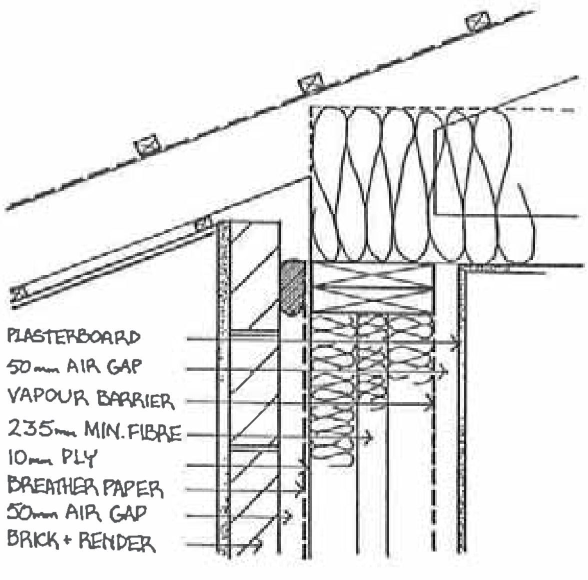
Much of the leakage could be attributed to changes in the location of the kitchen ductwork, which compromised the integrity of the polyethylene vapour barrier. After careful remedial work, the builder succeeded in reducing the air leakage to 1.94 ac/h at 50 Pa.



Detail at window opening



Three layers of insulation installed in walls



Expanded truss detail to accommodate eaves insulation

TIMBER-FRAME

'Winslow' House

Services

Space heating: Electric air-to-air heat pump, located at first floor level and feeding a warm air system. It is made by Genvex, Denmark, and it is linked to the mechanical ventilation system, see below.

The heat pump is designed to provide the majority of the heat input to the house over a normal year. It can heat the ventilation supply air to as high a temperature as 45°C, and the calculated coefficient of performance (COP) is 3.4.

When weather conditions necessitate, or if the occupants desire more precise room-by-room temperature control, the heat pump can be supplemented by electric resistance panel heaters, which are controlled individually by mains-borne signalling. These have individual thermostats and can be programmed to come on at particular times.

Water heating: Off-peak resistance heating, large mains-pressure storage tank, insulated with approximately 50 mm of polyurethane foam.

Ventilation: Mechanical ventilation with heat recovery. It serves all rooms; stale air is extracted from the wet rooms and fresh air is supplied to bedrooms and living rooms. The speed is adjustable in stages by the householder.

Lighting: All ceiling and wall fixtures take compact fluorescent lamps. Most of them are four-pin lamps and are hard-wired, so the occupier could not easily revert to incandescent fittings.

Electrical equipment: Mostly energy efficient German models, chosen from those available on the UK market.

Cost

The construction cost was about 20% more than Admiral Homes' usual speculatively built timber-frame houses. The firm considers that all walls which go beyond the 140 mm timber stud wall have a significant added cost, but given the choice, they prefer the double-wall concept to I-beams. This is because it has less thermal bridging and is more flexible and readily available.

Energy consumption

The estimated space heating costs were £61 per year. The Standard Assessment Procedure (SAP) home energy rating is 100, the maximum score possible. This assumes that the house is preferentially heated by the heat pump and that resistance heating is only used as a top-up.

Energy carrier	Purpose	Cost £/yr
Electricity	Space heating	61
Electricity	Water heating	90
Electricity	Cooking	69
Electricity	Lights and appliances	222
Electricity	Standing charges	56
TOTAL		498

Estimated energy costs

Other operating costs were also calculated; these are set out in the table above.

However, no bills are yet available. The note below includes further information on energy costs.

Experience/feedback

The house was sold before the exhibition opened. The purchaser considers it to be the most comfortable house that he has ever lived in, and much superior to his previous house which was built in Milton Keynes around 1990.

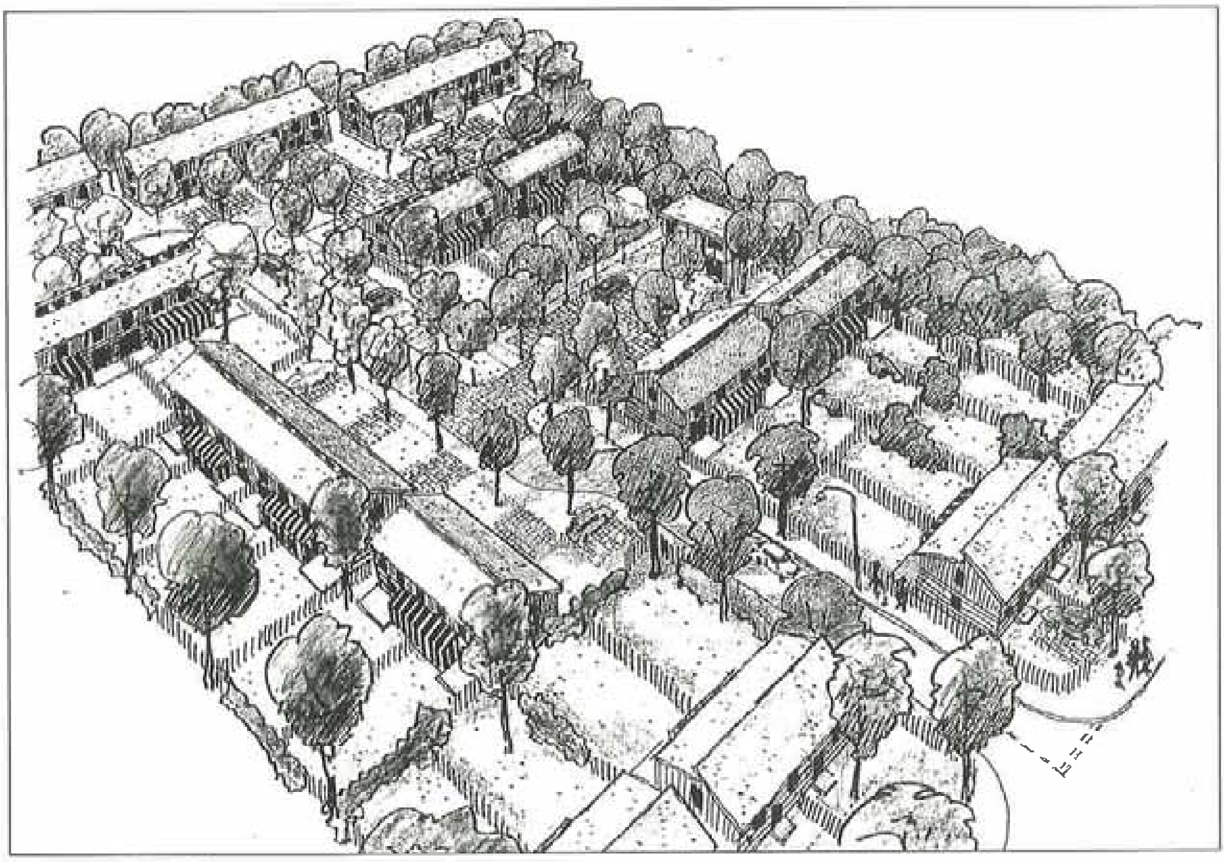
The mechanical ventilation system is liked because it is perceived to give a healthy indoor environment. No condensation has ever been observed, even on the base of the triple glazed windows.

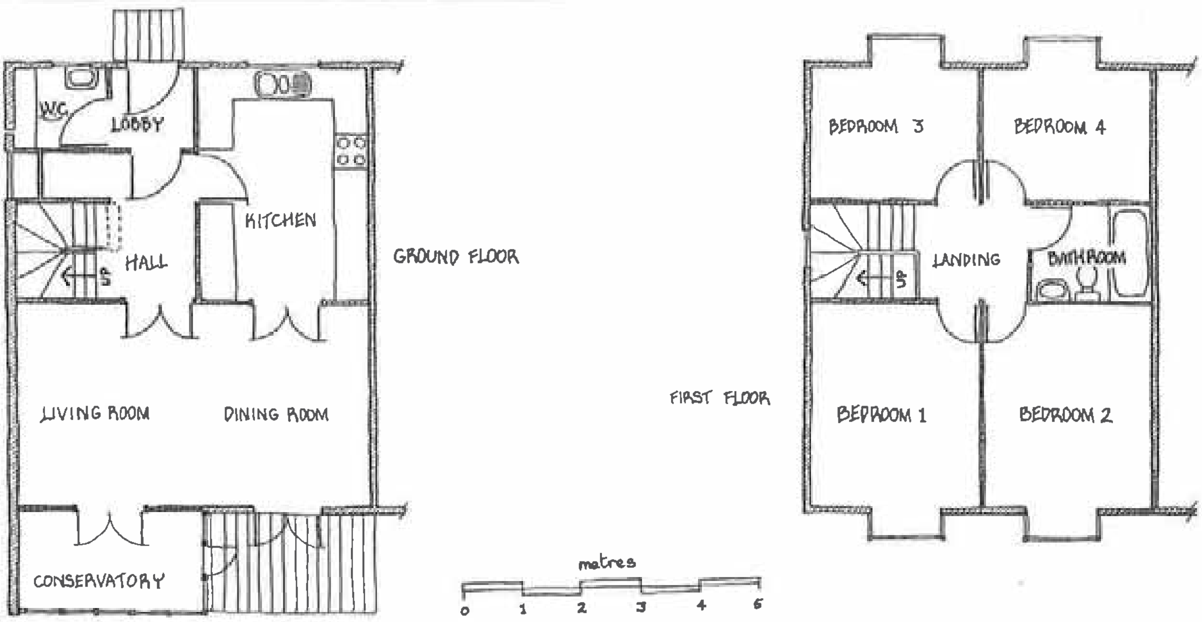
For a while after the house was occupied, space heating costs were higher than expected. Eventually this was traced to incorrect operation of the heating system control. This was recommissioned so that space heating priority was given to the heat pump rather than the electric resistance panels. In addition, for a time, it was found that the hot water had been heated by on-peak electricity rather than off-peak.

The house gained an excellent Building Research Establishment Environmental Assessment Method (BREEAM) rating. The BREEAM procedure has been amended by a new award, entitled Environmental Standard: Homes for a Greener World. This was launched by the Building Research Establishment in April 1995.

TIMBER-FRAME SITE-BUILT

Birchdene Drive Self-Build, London (1994)





Client	Greenwich Self-build Co-op and London and Quadrant Housing Association
Architect	Architype Design Ltd, Southwark, London

TIMBER-FRAME

Birchdene Drive Self-Build

Nature of the buildings

A development of 12 semi-detached two-storey houses; the floor area of each is 92 m². Four bedrooms, one bathroom.

Progress on constructing the houses was slower than normal for timber-frame buildings, as the self-builders were working mainly at weekends.

Background

This is the third self-build scheme constructed by Greenwich Self-Build Co-op, using the CHISEL self-build for rent model. The scheme is forming the focus for the development of Thamesmead Sustainable Village Development. This will integrate low-energy housing with employment and training and wider issues of sustainability and autonomy.

After several visits by the architects to Scandinavia, a new and innovative energy efficient self-build system was developed in conjunction with the Swedish timber company, Masonite AB. The firm manufactures I-beams with softwood flanges and hardboard webs.

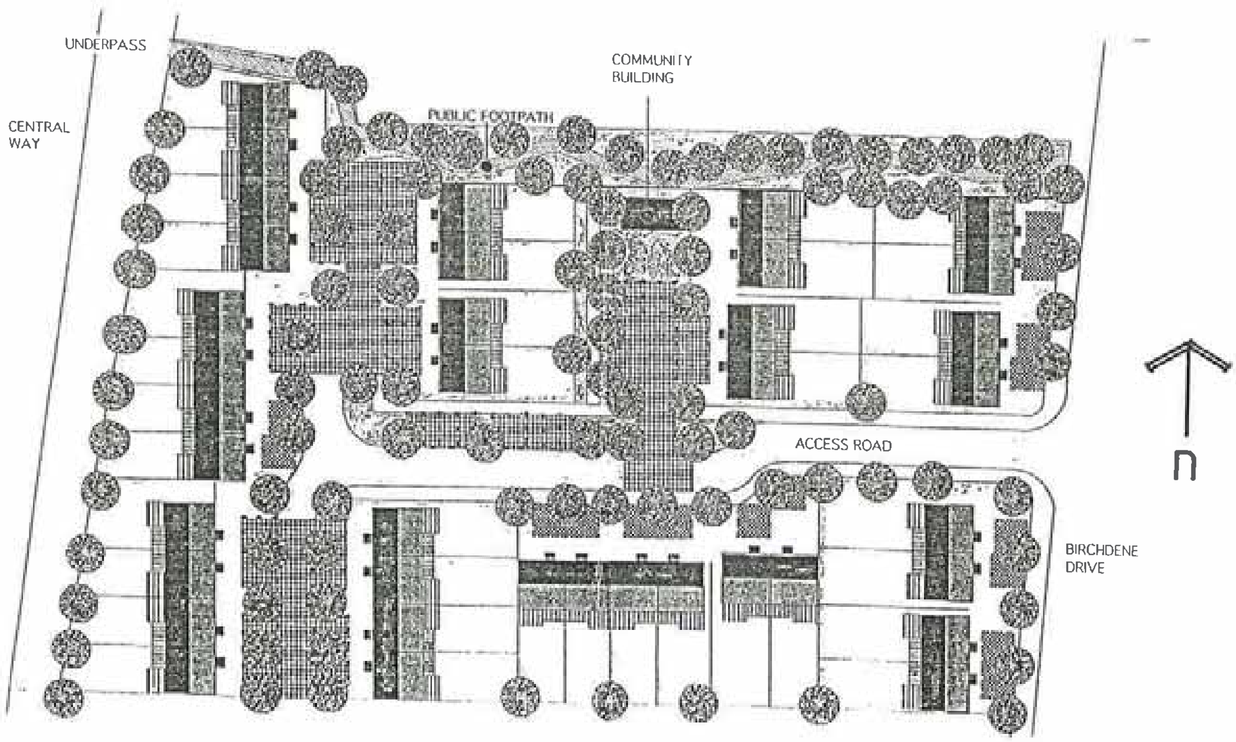
These composite elements are suitable for many applications where solid timbers would otherwise be used. The beams and studs are stronger, lighter and easier to handle than solid timber. They are arguably more 'ecological' since the manufacture of the webs uses smaller trees and utilises waste from machining, and they achieve a greater continuity of insulation.

The beams have been used in Scandinavia for over 20 years, but have been used very little in the UK. It was shown in Sweden and Denmark some years ago that I-beams were usually a cheaper way to attain very high insulation levels in timber-frame buildings than the use of ever-larger solid timber studs.

All the structural calculations were carried out by the practice's own engineer. The architects have consistently found this to be more satisfactory for the timber-frame structures they design, which usually differ from the standard timber-frame designs.

The site is a reclaimed marsh. The ground conditions are so poor that the designers had to use deep concrete piles and ground beams. As a result, the use of stud walls was felt to be more appropriate than the post-and-beam system used in many of the architects' previous projects.

The self-builders are very inexperienced. An experienced tradesman was hired to act as contract manager on this site and others in the development. He provides day-to-day supervision of general building operations, to help reduce the risk of mistakes. One of the self-builders has been appointed assistant to the contract manager on this particular site, and is providing more detailed supervision.



Site plan

TIMBER-FRAME

Birchdene Drive Self-Build

Fabric

Floor: Chipboard, 75 mm of cellulose fibre insulation between battens, concrete slab (U-value = 0.39 W/m^{2}K). This slab in turn rests on ground beams and concrete piles.

Walls: Plasterboard, sealed at seams, 170 mm I-studs on 600 mm centres, filled with cellulose fibre, lined externally with bitumen-impregnated softboard and clad in home-grown Douglas fir (U-value = 0.25 W/m^{2}K). The party walls are also timber-frame, but for acoustic reasons they contain even more insulation, and the building control department required an additional slab of mineral fibre as fire protection between the houses. This fire barrier was placed between a double layer of I-studs.

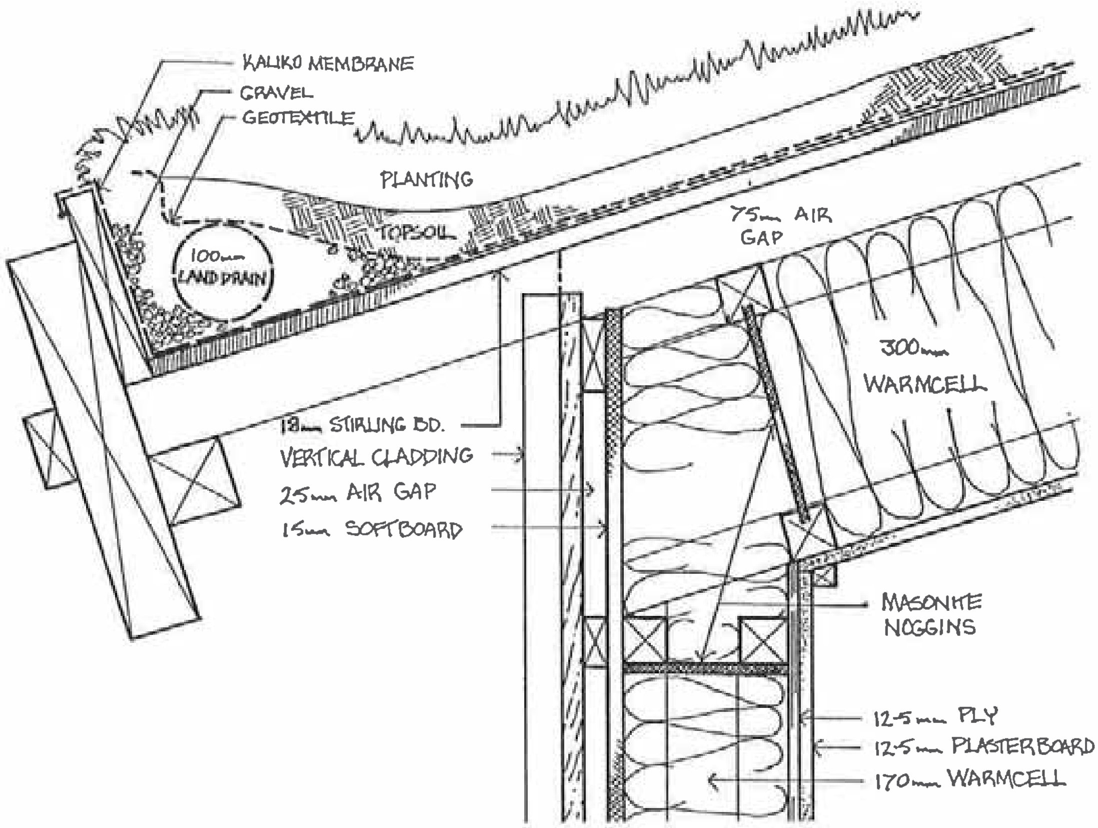
Roof: Pitched roof. Plasterboard, 350 mm deep I-beams with 50 x 50 mm softwood flanges and 5 mm hardboard webs, insulated with cellulose fibre, bitumen-impregnated fibreboard sheathing, ventilation gap (U-value = 0.12 W/m^{2}K). Followed by an external timber deck covered with a PVC waterproof membrane and finished with a grass and wild flower roof. The soil on these roofs will be approximately 100 mm thick.

Windows: Planned to be double glazed with one sputtered low-emissivity coating, in wood frames (U-value = 2.1 W/m^{2}K). They will be either of Danish or UK origin, depending on cost.

Air leakage: Not yet known. The houses utilise 'breathing' wall and indeed roof construction, with no polyethylene vapour barrier.

It is recognised that there is a need to make the inner face of such timber-frame structures not only less vapour-permeable than the outer layers but as airtight as possible. On this scheme, an attempt has been made to reduce air leakage through all parts of the fabric.

Wall panel being raised into position



Eaves detail, showing the turf-covered roof

TIMBER-FRAME

Birchdene Drive Self-Build

Services

Space heating: To be by individual gas-fired condensing boilers, Dataterm boiler energy managers and thermal store.

Water supply and treatment: The plan is for rainwater to be collected from the roof to flush WCs. It is intended that greywater will also be collected and treated for re-use. The extent to which this happens depends on funds being available, over and above the cost quoted below.

Other environmentally beneficial features

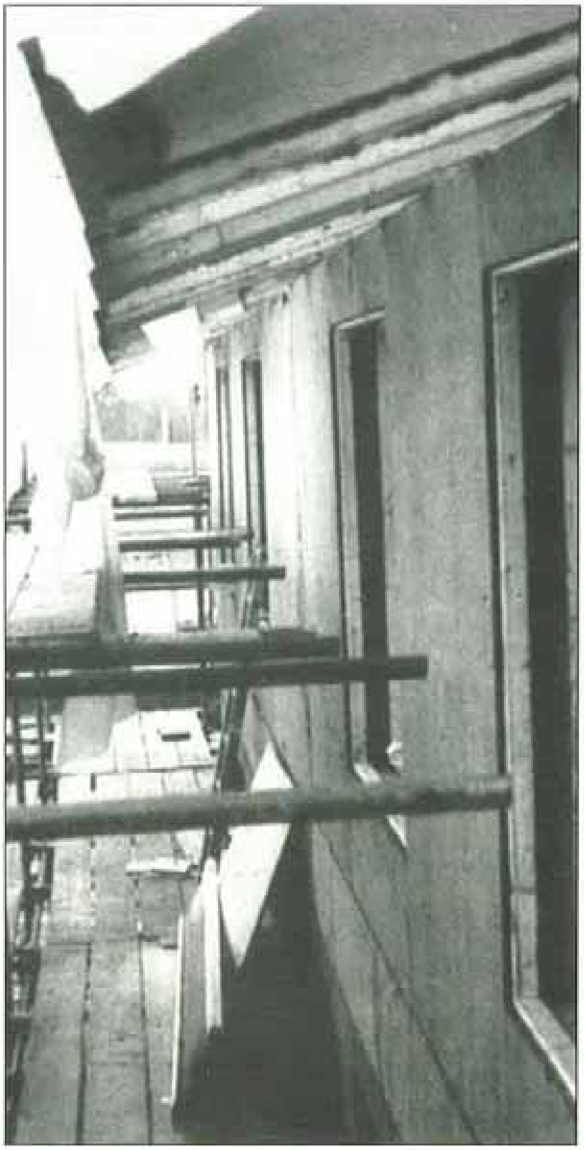
The houses use home-grown timber external cladding, organic non-toxic stains and paints, and natural floor finishes. The grass roof is seen as making a positive contribution to the local environment, by absorbing CO_2 and heavy metals, providing a wildlife habitat and giving a pleasant outlook.

As regards the PVC membrane on the roof, this material is coming under increasing environmental pressure, but it does have some useful properties. In particular, on this job, the ability to heat-seal the seams will make it much easier for self-builders to install than some other membranes.

Cost

The total building cost is £370/m^2. This excludes the value of the labour input by the self-builders, who are installing the above-ground structure and the services. It includes the contractor's price for the pile foundations and concrete ground floor slab.

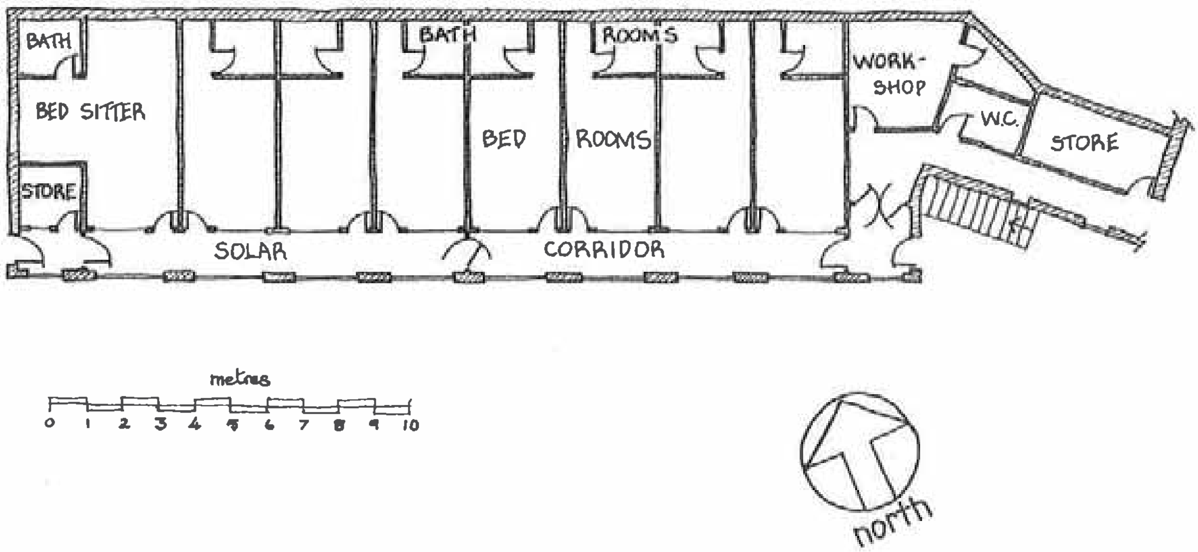
The overcost is not known. In the UK, built-up I- and box beams cost more than the same dimension of solid timber, but there are indirect savings. For instance, because of their greater span, they need fewer support walls or beams, and because of their reduced thermal bridging, one can produce a thinner wall with the same thermal resistance. A 170 mm wall with I-beams could possibly have as good an energy performance as a 200 mm thick wall using normal solid studs. The structure based on I-beams is certainly no more expensive than a conventional timber one.



Overhanging eaves detail

EARTH-SHELTERED

The Berm House, Caer Llan Field Studies and Conference Centre, Lydart, Monmouth, Gwent (1987)



Designer and Owner	Peter Carpenter
Concrete, Brickwork and Stone Masonry	Bryn and Roy Boycott, Wye Building Contractors Ltd
Joinery	Gerald Harris, Monmouth

EARTH-SHELTERED

The Berm House

Nature of the building

The building is a 363 m² extension to a guest house. It comprises a staff flat and a row of seven guest bedrooms, all with en-suite bathrooms. The structure is built into a SSW-facing slope, with a 'solar corridor' along the south side.

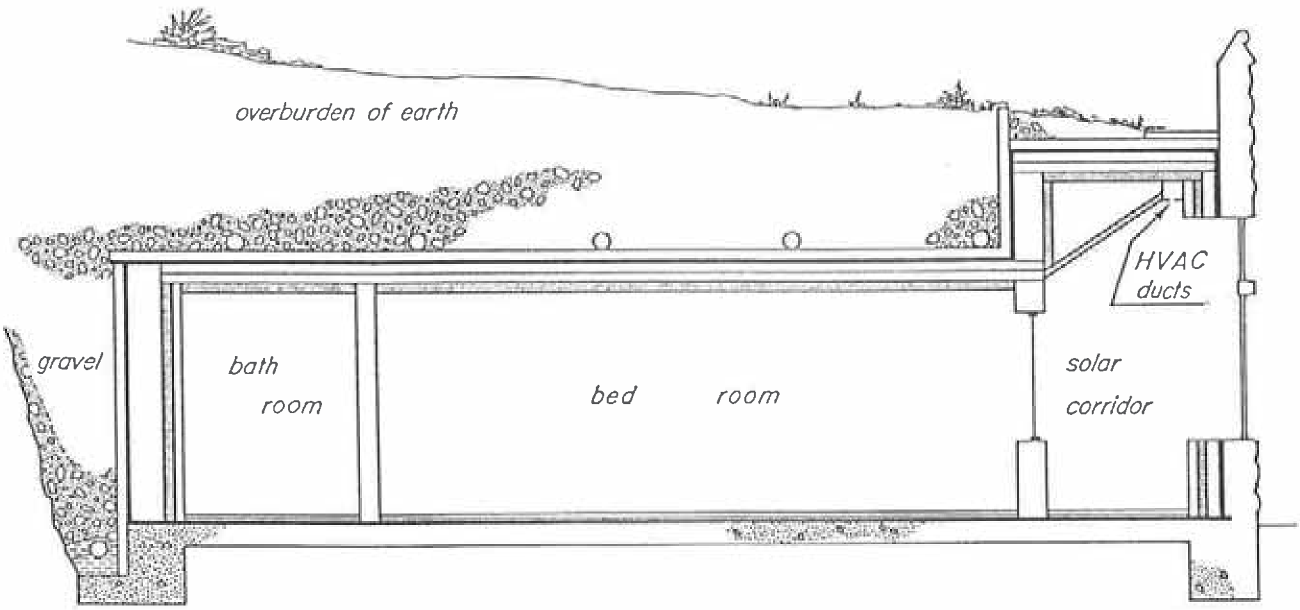
The building is sited well above the spring line. The underlying soil is reasonably dry and there is no risk of a problem due to moving groundwater.

Background

The project was conceived in 1980, and a paper was presented to the Solar Energy Society Conference in Brighton in 1981. From the start, the aim was to reach zero space heating energy, and to reduce the building's maintenance costs to an absolute minimum. Both of these aspects provide a stark contrast to the existing 19th century house, which has been run as a field studies and conference centre since 1970.

At an early stage, as an insurance policy, it was decided to insulate internally, so that visitors could heat a room up easily with a portable electric heater if necessary.

View along the solar corridor



Cross-section through the Berm House

EARTH-SHELTERED

The Berm House

Fabric

Floor: Carpet, screed, 12.5 mm polyurethane foam, bituminous tanking, reinforced concrete raft, hardcore (U-value = 0.65 W/m^{2}K).

Walls:

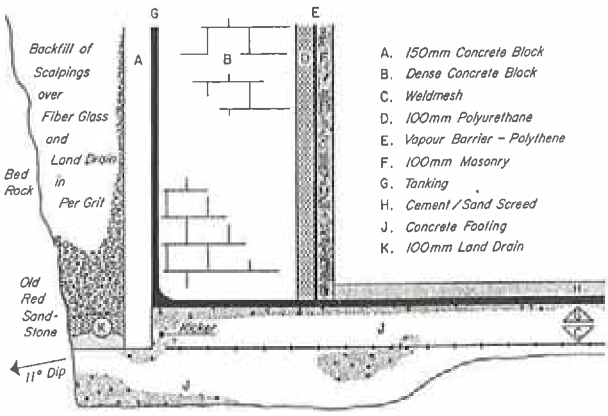
(1) South wall – 100 mm clay brick, 100 mm polyurethane foam slabs, 225 mm dense concrete block, tanking, 200 mm local sandstone (U-value = 0.17 W/m^{2}K). The insulation slabs throughout the building are sealed at seams with in-situ polyurethane foam.

(2) North retaining wall – 100 mm fair-faced clay brickwork, polyethylene vapour barrier, 100 mm polyurethane foam slabs, 660 mm dense concrete block, tanking, 150 mm dense concrete block (U-value = 0.16 W/m^{2}K).

(3) West wall – same insulation as the south wall, but contained within a leaf of 150 mm and a leaf of 300 mm concrete block. This wall was designed as a retaining wall to bear a substantial earth load, but is now being partly rebuilt to allow for the building's westward extension. For details, see page 54.

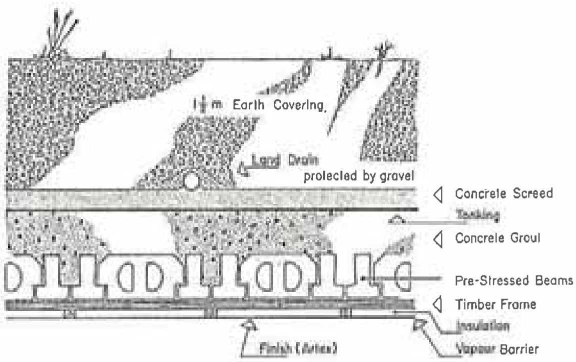
(4) Load-bearing cross walls – 102 mm fair-faced clay brickwork, 25 mm cavity, second leaf of brickwork, all on 4 m centres.

(5) Between guest rooms and corridor – 102 mm fair-faced brickwork, black-coloured.



Retaining wall construction detail

Roof: Internal fire-resistant finish of 'Artex', aluminium vapour barrier on inner face of 100 mm polyisocyanurate foam slabs, 200 mm concrete beam-and-pot deck with alternating pots and double beams, 100 mm in-situ reinforced concrete, tanking, 75 mm in-situ concrete, 1.5 m earth with gravel and land drains at intervals, grass and flower beds (U-value = 0.14 W/m^{2}K).



Roof construction detail

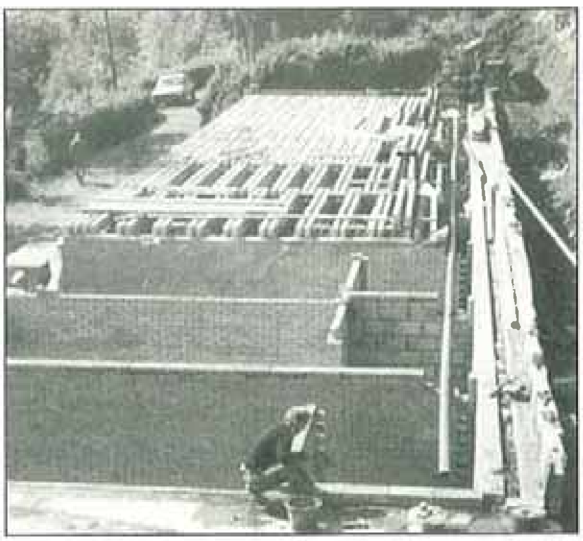
Windows:

(1) Solar corridor – 12 mm air-filled double glazing with one sputtered low-emissivity coating, in aluminium frames, and with reconstructed sandstone mullions, set in turn in the stonework (U-value = 2.6 W/m^{2}K). No thermal break in the aluminium or stone. The total south-facing window area is 16% of the building floor area, and the building has no other glazed area.

(2) Between guest rooms and corridor – single glazed, in beech frames.

External doors: Solid timber from yew and other hardwood cut from the site and air-dried, with 6 mm air-filled low-emissivity double glazing (U-value = 2.5 W/m^{2}K). Moderately well weatherstripped. There are double doors between the solar corridor and the outside air, with a small draught lobby in between.

Air leakage: Not measured. Probably low. The south wall is tanked and all the windows are fixed and sealed to the tanking.



Precast roof beams being installed. Note ventilation duct to bathrooms on right

EARTH-SHELTERED

The Berm House

Services

Space heating system: None.

Ventilation: Continuous mechanical. Supply to corridor and extract from bathrooms. Both ducts run the length of the building and have in-line fans. Over part of their route, concentric ducts are used. The supply air recovers a certain amount of heat from the exhaust air. The proportion is unknown.

The winter air supply to the corridor enters through a grille, placed at ceiling level to minimise draughts. In summer, two vents at the base of the south wall are opened to admit air, which rises to the ceiling and is drawn into a duct from which air is supplied to the guest rooms. Air enters the rooms via airbricks in the cavity cross walls.

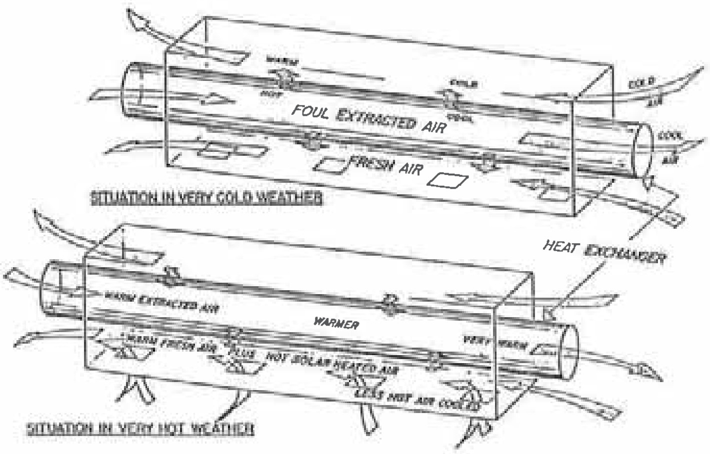


Diagram of the mechanical ventilation system

The normal rate of fresh air supply to the whole building is 360 m^3/hour, and the total rate of extract from the eight bathrooms is the same. When a bathroom light is switched on, a supplementary fan triples the extract rate from that individual suite.

Hot water: A recirculating loop, taken off the oil-fired boiler in the main house, supplies each basin, bath and shower. It is boxed-in with timber but is otherwise uninsulated.

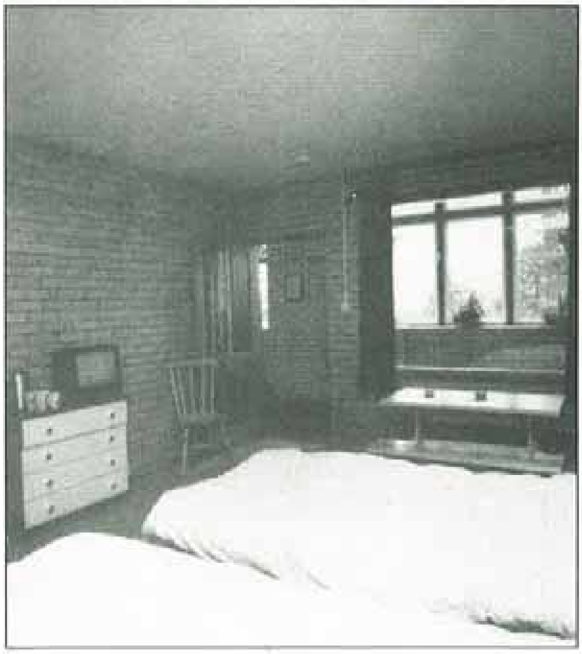
Electrical lighting and equipment: 13 W compact fluorescents in the corridor, the bathrooms and bedroom ceilings; 25 W incandescent reading lamps also provided. All other equipment, eg kettles, TVs, is of average energy efficiency.

Environmentally beneficial features

The structure was designed for long life and low maintenance. In fact, zero external maintenance was the aim, and this led to the selection of the aluminium windows and other features. The building contains no gutters, external timber, paint, putty, plaster, floorboards, wallpaper or similarly maintenance-intensive items.

Energy consumption

Space heating energy: Zero. The normal annual range in air temperature in the guest rooms is from 17.5 to 24.5°C. In recent mild winters, the minimum temperature has been 18°C. The minimum temperature in the corridor, which is not intended to provide full comfort conditions, was about 13°C in the early years and has recently been 14-15°C.



Bedroom interior, showing view through solar corridor

Ventilation electricity use: 5 kWh/m^2yr.

Total electricity use: 14 kWh/m^2yr.

Hot water use: Unmetered; the recirculating loop is boxed-in with timber at the back of the bathrooms, but is otherwise not insulated.

Cost

The structure was built on a direct labour basis for £330/m^2. The arrangements with the separate trades were very informal. However, detailed cost records were kept.

EARTH-SHELTERED

The Berm House

Experience/feedback

Drying out took three years. Some use of a dehumidifier was necessary for a number of weeks. After that, despite a number of apparent thermal bridges in the fabric, the energy performance has been excellent.

The earth cover is providing a good time-lag. Next to the building, the measured temperature of the earth was 11.6°C in January 1995.

Window installed directly into stonework, to give low maintenance costs

The minimum air temperature of 17.5-18°C has given rise to few complaints. The guest rooms are used mainly for sleeping in, and the radiant temperature is the same as the air temperature.

The performance fully bears out the owner's initial thermal calculations, but confounds the predictions of many thermal simulation models. Some of these models predict that the Berm House should consume as much as 30 kWh/m²yr of space heat. It is clear that the models simplify the three-dimensional heat flow in the soil, and the heat flow to and from the thermal mass.

First layers of soil being installed above roof drainage system

The Department of Energy, which made some short-term measurements, found that all the temperature graphs showed straight lines. This was correct; the room air temperatures in the Berm House show no diurnal variation, which is very unusual.

The air temperature has changed by ≤1 K in all months since 1987, with the exception of one very wet September. On that occasion, the owner observed a quite rapid drop in the internal temperature in the bathrooms, which fell by 2 K. This was apparently caused by the heavy rainfall carrying large amounts of stored heat out of the soil. The same phenomenon has been observed in earth-sheltered buildings in the USA.

The owner reports that in winter the bathrooms run at a mean temperature of 0.5-1 K above the adjacent sleeping rooms. This suggests that although the heat gains from this source have some effect, it is a modest one.

The staff flat has permanent heat gains from the occupant(s) and from electrical appliances. Its air temperature has consistently been 1 K higher than elsewhere in the Berm House.

Opinion is divided over whether internal insulation of the earth-sheltered walls was appropriate, given the risk of interstitial condensation on a waterproofed wall. The owner does agree that if the structure was built again, it would be preferable to insulate the exposed south wall near to its outer face, and not near to the inside.

There have been no serious complaints about the standard of thermal comfort in summer. On hot days in June, the rooms actually feel cold to enter. However, it is recognised that the cooling capacity of the mechanical ventilation system is marginal during heatwaves. In the hotter summers, the air temperature of a bedroom creeps up to 24-25°C after it has been occupied by a family of three or four for a few days.

If starting again was an option the owner would make some changes, including fitting opening windows to the corridor. The building would then operate in a 'mixed mode' manner and would be naturally ventilated in summer. To an extent, the effect of natural ventilation was simulated over the summer of 1993 when staff left the corridor doors propped open. In that summer, the air temperature within the guest rooms did not rise much above 22°C.

EARTH-SHELTERED

The Berm House

While this definitely improved summer comfort, it did not perceptibly worsen the building's performance in the subsequent winter. Now that the Berm House is known to be so tolerant of such changes, it is operated this way in summer.

The owner would also use the correct 150 mm diameter plastic ducts, rather than 100 mm ducts. This increase in airflow would improve summer comfort. It also has implications for the electricity consumption.

The next project on the site is to be a non-residential building. Built into the hillside to the west of the Berm House, this will be a zero-energy swimming pool and conference hall.

The south facade, viewed from the south-east

Conclusions/issues arising

The in-depth review of these ten schemes, together with the analysis of 52 schemes in Phase 1 (General Information Report (GIR) 38), results in findings as follows.

(1) *UK activity*

This review reveals that there is now significant UK activity in the area of ultra-low-energy homes. Seventy-four UK schemes were identified in Phase 1 which includes the 200-plus dwellings in the scheme at Strawberry Hill, Salford, and nearly 500 dwellings in total. They utilise a variety of construction techniques, and they were all expected to achieve high standards of energy efficiency.

However, this review shows that the energy performance of many UK ultra-low-energy homes falls below the level expected. It is essential that steps are immediately taken to identify the reasons for this and to ensure that the performance of future ultra-low-energy homes is improved.

Many of the factors below contribute to this discrepancy. See especially points (6) to (11).

(2) *Range of energy performance*

The 52 schemes reviewed in GIR 38 and GIR 39 span a wide range of energy performance. The standard of the least energy efficient schemes here is closer to normal new UK housing than to the state-of-the-art schemes, which make lavish use of a wide variety of technology.

Examining the delivered energy figures of the 52 schemes gives an excellent indication of this point. Where an energy consumption is quoted, it ranges from 9 to nearly 200 kWh/m^{2}yr. The minimum insulation and glazing standard, which all of the 40 UK schemes in Phase 1 would meet, corresponds approximately to the Building Regulations which applied to Sweden in 1980 or to Denmark's Building Regulations of 1985.

One could arguably describe projects like Great Linford and Pennyland in Milton Keynes as still 'one step' ahead of the UK 1995 Building Regulations. If the schemes in this report were placed on a scale of one to ten points – one being the 1995 Building Regulations and ten being a home occupied by an average family which uses no external non-renewable energy supplies – it is possible that some might obtain only three points. Longwood and Lower Watts might obtain five or six points, Caer Llan and Southwell seven or eight. By contrast, some overseas schemes might justify nine points. So might a few UK schemes now at design stage, if they manage to utilise equally advanced technology.

Few of the UK schemes had a published SAP, but if their design data was put into a SAP calculation many would receive 100.

(3) *Energy performance of UK schemes*

The energy consumption of recent UK schemes has not been fully monitored. To judge from the available energy bills, UK schemes are not performing as well as their overseas counterparts. The energy performance is poorer than overseas schemes of the same age, the same construction type and in the same market sector.

The original criterion was a total energy consumption, assuming a mixture of fossil fuel and electricity, of < 100 kWh/m^{2}yr. It was noted that < 60 kWh/m^{2}yr for all-electric schemes would be equivalent, in primary energy terms, to 100 for schemes using gas for space/water heating and cooking.

Some UK schemes, like Salford, Reyburn, Family Housing Association and Cresswell Road, are on the borderline, but only four – Longwood, Lower Watts, Caer Llan and Southwell – clearly meet this target. Only the last two use < 50 kWh/m^{2}yr.

Caer Llan is an earth-sheltered house built near Monmouth, South Wales, in 1986-87. It used the insulation and glazing technology of the mid-1980s, but its performance places earth-sheltered dwellings in a class of their own. Southwell is a masonry house built in Nottinghamshire in 1993. It was deliberately designed as an autonomous house which would need no energy input for space heating, except for a small backup woodstove.

The use of energy per unit area to measure performance creates a bias towards large dwellings. However, the fact that three of the top UK schemes are detached houses, which have an unfavourable surface-to-volume ratio, may in part offset this.

The authors consider that the poor energy performance of many UK schemes may be linked to unexpectedly high air leakage and to poor design and commissioning of space/water heating systems, plus other effects. See especially points (6) and (9) below.

(4) *Energy performance of overseas schemes*

Recent ultra-low-energy schemes in Canada, Germany, Switzerland and Denmark achieved a 70-85% saving in total energy use, compared with a typical house in the respective countries.

The energy consumption of the 12 overseas schemes ranges from about 9 to 90 kWh/m^{2}yr. Two large schemes in Germany and Switzerland are using 15-30 kWh/m^{2}yr.

The Canadian R-2000 Programme has produced quite a large number of homes that use energy at a rate of about 100 kWh/m^{2}yr – the original target for the UK. With the exception of British Columbia, the Canadian climate is distinctly colder than the UK's in winter and hotter in summer, so this is striking. Southern Ontario, the most densely populated part of Canada, has a similar number of degree days to Shetland, but the winter design temperature is about -20°C rather than about -7°C.

(5) *Construction systems*

(a) *Variety*

A great diversity of construction methods are compatible with very high energy efficiency standards. There is no need to change the construction system on energy grounds alone; other factors are likely to determine the preferred method. Most of the UK custom-built single houses and social housing schemes are of heavyweight masonry construction. Self-build is more evenly divided. Speculative ultra-low-energy developments contain a high proportion of timber-frame.

(b) *Modifications*

Both the timber-frame and masonry dwellings studied have been significantly modified from normal UK practice. In timber-frame, the vapour barrier or, in a few cases, the internal air barrier, was upgraded and protected against damage, and more care was taken to reduce thermal bridging by solid timber.

In masonry, steps were taken to reduce thermal bridging. The construction system for walls and floors moved closer towards the general approach used in Northern Europe. Timber roofs were improved in much the same way as in timber-frame buildings, and the vapour barrier was sealed to the plaster on the walls.

Without exception, all the UK cavity walls and externally-insulated masonry walls in Phases 1 and 2 were plastered. This seems a more efficient way to make masonry walls airtight than any of the other ways which have been suggested, eg applying a continuous bead of plaster behind the edge of each sheet of plasterboard. Where information is available on the UK masonry schemes, their upper floors are constructed as follows:

ten – concrete,
seven – timber,
three – a mixture.

The three earth-sheltered schemes also have concrete roofs.

Strawberry Hill (see GIR 38), the largest UK scheme, has concrete first floors. It was one of the first such UK low-rise housing developments.

The proportion of solid upper floors in this report is much higher than the UK norm. Solid upper floors may be an easier way to make the floor/wall junction airtight than to design airtight details for timber first floors, and then ensure that they are built correctly.

(c) *Innovative details*

On some UK schemes, designers used building details and techniques which had been developed and proven overseas, or even modified them further, rather than wait for them to be officially tested and proven in the UK. In this sense, one could say that 'practice is in advance of theory'.

However, it would be welcome if these same techniques were investigated in the UK. This would assist designers in the many districts where building control officers initially questioned the validity of novel approaches, even though most of them had been used overseas.

Some of these innovations may cost less than a conventional approach. Examples are plastic cavity wall ties, the use of plywood sub-frames or related details to close wide cavities, and the use of I-beams or double-stud walls in highly insulated timber-frame buildings.

(d) *Information resource – masonry dwellings*

A common question from designers is where they can obtain these products. In addition, although it is clear that masonry buildings can be built to a very high standard of airtightness, there is no literature resource equivalent to the extensive Canadian publications on timber-frame which contributed to the design details of at least three UK timber-frame schemes and the roofs of at least nine of the UK masonry schemes.

For instance, there is little data to indicate the differences in air leakage between the many different types of concrete floor possible in masonry buildings, or between monolithic and modular systems, eg poured concrete versus concrete masonry. In other details, too, UK designers have little guidance available. Several UK masonry schemes tended to rely on a limited number of Danish publications which dated from the 1970s, and more recently, on German and Swiss literature.

(e) *Information resource – timber-frame*

Timber-frame has tended to be better documented, and has often been promoted for its energy efficiency advantages. However, information flows in this area could also be improved.

(f) *Novel systems*

The review suggests that some heavyweight and lightweight construction systems which are uncommon in the UK are promising. Examples include in-situ and precast concrete, precast calcium silicate elements, timber I-beams and double-stud timber walls. These could all provide cheaper ways to reach very high insulation and airtightness than either hand-laid brickwork, concrete blocks or solid timber studwork.

They may also offer other environmental advantages. Calcium silicate and concrete appear to have a lower embodied energy content than fired clay or lightweight concrete products. Timber I-beams and double walls enable higher insulation thickness to be reached without using large timbers – which usually come from older trees and more sensitive areas of forest. I-beams are also applicable to the roofs of masonry buildings, and were used in several of the cavity-walled schemes.

It appears that the simpler technologies in UK schemes, such as 150 mm cavities, and fitting better-quality timber windows in a prepared opening, could be immediately applied by competent builders, given help and supervision. However, one would hesitate to specify the more advanced technologies, eg MVHR, on all sites.

(g) *Construction of overseas schemes*

The 12 overseas schemes are notable for the total absence of cavity walls. All the masonry-walled schemes in Denmark, the Netherlands, Germany and Switzerland are externally-insulated, albeit with a variety of materials and methods.

With this approach, the installation of the insulation can be treated as an entirely separate operation from building the structure. Since the associated skills tend to be quite different, this has advantages in terms of ensuring good workmanship.

(h) *Ground floor heat loss*

This remains a very uncertain quantity. In some cases, it was clearly overestimated. Conversely, at Caer Llan the actual insulation thickness used was 12.5 mm and it is clear that the owner correctly predicted the floor heat loss to be very low, owing to the favourable ground conditions.

(i) *Insulated external doors*

Over half the houses seem to have used these. The case is not hard to make.

(6) *Airtightness of UK and overseas schemes*

Only seven of the 40 UK schemes in Phase 1 have been tested for air leakage. Three are masonry and four are timber-frame. All the timber-frame schemes and one of the masonry schemes are in Milton Keynes.

The Phase 1 report shows that some overseas schemes were remarkably tight, with leakage of 1 ac/h at 50 Pa. The lowest was 0.2 ac/h at 50 Pa for some masonry houses in Switzerland and Germany and for a timber-frame house in Denmark built in 1978.

One UK scheme with 1 ac/h at 50 Pa was noted in Phase 1, Section 4. This scheme, in the Orkney Islands, is the only tested UK project which really begins to close this gap in

performance. Caer Llan, by its design, is probably very tight, but it remains to be tested.

Lower Watts House and Longwood are the tightest masonry houses yet recorded in the UK, with an estimated 2 and 3 ac/h respectively at 50 Pa. Longwood, which is described in GIR 38, had a knowledgeable builder, a simple shape and details which were not expected to be exceptionally tight. Lower Watts had construction details designed to be fairly tight, but a more complex shape and a local builder who had never built an energy efficient house before.

The actual outcome was that when they were first tested, the two schemes had similar air leakage. It appears that these opposing factors offset each other. It would be interesting to see the outcome either of a typical builder constructing a Longwood or a more experienced builder constructing a Lower Watts; air leakage would then probably vary widely. With the presence of a few large leaks, there is scope to make Lower Watts House much tighter.

The four timber-frame houses tested have air leakage ranging from 1.5 to 2.7 ac/h at 50 Pa. In the Winslow House, it took major efforts to reduce leakage to < 2 ac/h at 50 Pa. At Two Mile Ash(see GIR 38), the low leakage level of 1.5 ac/h at 50 Pa was achieved only through meticulous supervision.

The net present value of the difference in energy bills between a tight dwelling by UK standards (3-4 ac/h at 50 Pa) and a very tight one (< 1 ac/h) is probably comparable to the cost of the test. Therefore, to private householders, it may not really be profitable to carry out a test, neither is it cost-effective to spend two days making a house marginally more airtight. However, from a national perspective, it is very important to know to what extent the houses met their design values and where the main air leaks occurred, etc.

It would not be necessary to test all homes if builders understood which measures were effective and which were not. At present, this knowledge is almost totally absent from UK site practice, especially masonry housing. Ready access to such information would enable the UK to move more rapidly towards ultra-low-energy housing.

(7) *Air and vapour barriers*

Research indicates that air movement, not diffusion, is responsible for most cases of moisture damage in timber-frame buildings. Recent research suggests that some types of timber-frame walls may be constructed with no polyethylene vapour barrier, just an air barrier.

Two of the timber-frame schemes in GIR 39 have 'breathing' walls, and two have a polyethylene vapour barrier. Their relative success is likely to depend on which achieves better levels of airtightness. There appears to be little UK data yet.

In the debate on 'breathing walls', diffusion, convection and dynamic insulation have become confused at times. In principle, such walls are only following the same principles as heavyweight walls. Most of these utilise the plaster or a monolithic material (eg concrete) as an air barrier, and have no vapour-proof layer.

(8) *Ventilation systems*

There is resistance to mechanical ventilation with heat recovery (MVHR) systems by some architects. This led to several schemes utilising passive stack ventilation systems.

In part, this opposition was based on the belief that the power needed to drive the fans uses more energy than it saves. In fact, this is not always so. The electricity consumption per unit of fresh air delivered varies by a factor of 3. However, problems were also reported with passive stack ventilation.

The electricity consumption of current MVHR systems does give cause for concern. The electricity used to drive the fans can offset a substantial part of the space heating energy saved. More seriously, two of the UK schemes with MVHR systems, both of non-Scandinavian manufacture, do not appear to be receiving their claimed fresh air input.

Where MVHR systems work well, however, owners are clearly delighted. Condensation has been totally eradicated. In some houses, clothes are dried indoors in winter without any further energy use.

It is a cause for concern that mistakes made abroad in the past are now being made in the UK although the issues of high electricity use and poor performance could probably be resolved without major cost implications. The underperformance was noted in Canada 15 years ago. There it was overcome by comprehensive testing of systems, publication of the results and steady tightening of the standards, so that poor systems were forced off the market. Training and certification of installers was also important.

The fanpower issue appears to have been resolved, at least in principle, by the use of better ductwork, fans and motors. Two Mile Ash reached a tolerable electricity consumption in 1985, and fanpower is hardly an issue in some overseas schemes, which use as little as 18 W. A lower electricity consumption has now been enforced by the Canadian authorities in their Advanced House Programme, and by the new German Building Code.

It was surprising that no UK schemes had whole-house exhaust-only ventilation, despite its potential merits. In dwellings which are not extremely airtight, this can be a better investment than MVHR.

There is no direct evidence from this review, but the need for ventilation may be much lower where great care is taken to use non-polluting indoor materials. Southwell is a possible example.

(9) *Space and water heating systems*

Many schemes were let down by their space and water heating systems. Some had inappropriate or over-complex ones.

Four out of the eight completed schemes in this report had problems with the heating system. On a fifth, the Reyburn House, the problem may be minor but it is hard to comment until the thermostat is replaced and moved to its final location. On a sixth scheme, Cresswell Road, there is a discrepancy between the gas consumption of the two houses. This raises a possibility that barring construction defects, one of the heating systems may have problem(s). The two remaining schemes, Caer Llan and Southwell, have respectively no heating system and a point heat source.

Examples of the problems seen in the schemes, taken from profiles in both GIR 38 and this report, are:

- an oversized and uncontrollable solid fuel heating system at St Harmon,
- a large collection of complicated and expensive systems at Auton Croft,
- installation and commissioning problems at Two Mile Ash, TTL and Winslow,
- complex controls at Lower Watts, which would not have been commissioned properly in a smaller house, and might have wasted fuel rather than saved it,
- a poor quality control in the Reyburn Residence.

Some aspects of Two Mile Ash were conceptually good. To combine the heating and the ventilation services makes sense if the peak heat demand is very small. At Two Mile Ash, though, high and uncontrollable heat losses from the thermal store drastically undermined an otherwise ultra-low-energy scheme.

If these problems are an issue in energy efficient schemes, and if Lower Watts really is the UK's third most energy efficient home despite known problems in workmanship and commissioning, one can only speculate on the scale of the problem in more 'ordinary' dwellings.

Experience suggests that it is a waste of scarce resources to put complex heating services into a dwelling which has a highly insulated, airtight building envelope. Nothing illustrates this better than the Auton Croft, Hull and Gateshead schemes, which were reviewed or noted in GIR 38. Had the extra expenditure on mechanical services in these homes been reallocated to improving the thermal envelope and installing heat recovery ventilation, it might have almost eliminated the need for external energy supplies for space heating. Some UK schemes at design stage are indeed trying to do this.

If high levels of insulation and airtightness do become widespread, there will be a pressing need for simple, low-cost and low-CO_2 space and water heating systems. Examples which seem to be worth pursuing are gas/LPG water heaters with a simple loop which provides space heating via radiator(s) or a heater battery in the ventilation ductwork, and, at least in the rental market, for terraced housing and flats, district heating from central condensing boilers.

Opinions differ on exactly how much the heating system can be downsized and simplified, as the heat loss is reduced and/or the thermal capacity is increased. Experience from some overseas schemes suggests caution. The mean demand over the period from autumn to spring is indeed dramatically reduced, but the peak heat demand under extremely cold and/or cloudy conditions is reduced much less. The rate of heat input needed to warm up the building in severe weather could also be a constraint.

Some designers consciously took a decision to install full central heating in some social housing schemes. They did so on the grounds that low-income households might perceive a house with only a few radiators as 'sub-standard'. However, education should render this expensive step unnecessary in future.

(10) ***Geographical distribution of UK schemes***

Large parts of the UK have no ultra-low-energy homes at all. The far south, northwest England, northern England, Scotland and Northern Ireland have very few. Most of these regions are colder than average and would justify the use of these standards more easily than such places as London, Oxfordshire and Wales.

Some of the clustering of schemes can be attributed to the presence of local specialists or to active enthusiasm and involvement at local government level. Projects in 'new' areas could be even more valuable as exemplars.

(11) ***Tenure of UK schemes***

There is a sharp contrast between activity in the self-build/custom-built/social housing sectors and in the speculative market. Whereas speculative builders are responsible for the majority of new UK homes, the bulk of these ultra-low-energy schemes were or are being designed and built for a particular owner.

The UK building industry takes a very short-term view, given that few UK house-buyers apparently understand energy efficiency issues or stay in a home long enough to repay even a modest overcost. By contrast, it is clear that self-builders, individual clients having a home custom-built, and housing associations, are prepared to incorporate higher energy efficiency standards than most speculative builders, but do ask that items are prioritised, so that limited budgets are well-spent. However, self-builders are often unaware of the feasibility of wider cavities, better-quality wood windows and the need for more airtight construction.

The 40 UK schemes show the following cross-breakdown by tenure and construction type.

MASONRY AND CONCRETE
(INCLUDING EARTH-SHELTERED)

Self-build *	8 schemes
Custom-built	8
Social housing	7
Speculative	3
TOTAL	26

TIMBER- AND STEEL-FRAME

Self-build *	4 schemes
Custom-built	2
Social housing	0
Speculative	8
TOTAL	14

** Some social housing schemes are also self-build; they were classified as the latter.*

About 75% of custom-built and social housing schemes are in masonry, but the position in speculative housing is reversed and timber-frame constitutes 70% of all schemes. The sample size is quite small, but there appears to be a genuine difference here.

Flats were entirely absent from the UK sample. This may reflect the fact that there are not many self-build flats, and that by chance, the social housing schemes which were reviewed in Phases 1 and 2 comprise entirely semi-detached and terraced housing.

(12) ***UK costs***

Where an overcost is given for the ten UK schemes, it varies widely, from zero for the Cresswell Road and Lower Watts cavity walled houses to up to 20% for the Winslow timber-frame house at Futureworld. Where a construction cost is quoted, it ranges from about £250/m² floor area to over £900/m². Southwell has four different types of floorspace, and Lower Watts has a double garage in addition to the house.

Experience suggests that other factors greatly affect the construction cost of a house and may have more influence, by themselves, than energy-conscious design. These include the complexity of its shape, the type of materials, and the management skills shown in its construction. The scatter of costs here tends to bear this out.

The final contract sum is known for only three projects – Lower Watts, Cresswell Road and Southwell. Several others are self-build. The costs at the bottom of this £250-900/m² range exclude either some of the owner's management time or even the value of the labour provided by the self-builders.

Even allowing for this, it is most unlikely that these overcosts were calculated on the same basis. Some of the lower costs may be attributable to other cost-saving steps which could be taken anyway and can be seen in several schemes, eg providing floorspace within a 'warm' roof, making the thermal envelope simple in shape and accepting shorter spans, eg by load-bearing cross-walls in the heavyweight buildings.

Several UK designers commented that, in the short term, one must add even more to the cost to reflect the time-consuming effort needed to communicate to a UK workforce what is different on an ultra-low-energy dwelling, and why some details must be built differently.

Much depends on careful workmanship and on an understanding of exactly why one is doing certain things. One of the largest differences between countries is that the standard of site practice appears to be consistently poorer in the UK. This results in a greater need for supervision for equal results.

A consequence of this is that the initial costs of implementing a package of measures may be greater than the costs of the measures alone and considerably greater than the potential long-term cost, if the package of measures were universally used and mass-produced.

Overall, it appears that this range in costs dwarfs the quoted overcosts for the energy efficient measures, and that with careful design the overcost need not be high. However, further work would help confirm this.

(13) ***Cost of overseas schemes***

The construction overcosts of several overseas schemes which use 30 kWh/m²yr of delivered energy seem to be 5-10%. Thus, with the use of 1989-90 technology, Wadenswil and Darmstadt both had a 10% overcost and both use about 30 kWh/m²yr. The designers of Darmstadt thought that the overcost would fall to 5% if all the materials were mass-produced.

Differences from the UK make it hard to draw definite conclusions. First, the overseas schemes, and the base case against which they are costed, are more energy efficient than the UK schemes. Wadenswil appears to have been costed with the Zurich Building Code, which normally requires triple glazed windows, as a base case. Also, some overseas schemes, such as Hjortekaer House G, are rather old, and one might do better now. Energy efficient glazing, in particular, has advanced far in the last ten years.

(14) ***UK/overseas comparison***

The finding is that only four UK schemes clearly use under 100 kWh/m²yr. This result is very disappointing. The performance of UK schemes is not as good as their overseas counterparts, often by a large margin.

This seems to be linked to several factors. Among them are the pace at which information is disseminated, the current nature of the UK building industry, the UK's historical attitude to energy efficiency and the way in which the funding situation varies between countries (see below).

This statement does not imply that all other temperate/cold countries do 'better' than the UK. Some, like France and Belgium, actually appear to have many less ultra-low-energy schemes. There is a large variation between countries with seemingly similar climates; the bulk of the ultra-low-energy schemes are to be found in a few countries which maintain a consistent lead in this field. Broadly speaking, these regions are North America, Scandinavia, Germany, Switzerland and the Netherlands.

(15) ***U-values in the UK***

(a) *Floors, walls and roofs*

Real U-values for glazing, timber-frame walls, etc are higher than many quoted in the literature.

Many stated U-values for timber-frame elements seemed to be particularly low. Based on recent US field measurements, allied to the calculations in the 1993 ASHRAE Handbook of Fundamentals, the actual U-value of a typical stud wall with 140 mm mineral fibre is not likely to be about 0.2 W/m²K, but more likely to be about 0.35 W/m²K.

More realistic U-value calculations are needed in walls, roofs and floors. This is both for design purposes and to allow like-for-like comparisons between alternative constructions.

In general, the discrepancy between simplified U-value calculations and more elaborate methods becomes larger in ultra-low-energy housing than in normal dwellings. Many of the standard assumptions which are made during thermal calculations may become very optimistic when dealing with highly insulated dwellings.

(b) *Glazing*

Most of the glazing U-values quoted for the UK buildings come from manufacturers' literature.

The accepted U-value for a plain triple glazed window, in a wood frame, with two 12 mm sealed airspaces, is around 2.1 W/m2K. Not all products in the ultra-low-energy dwellings reached this figure, although most designers clearly expected that they would.

Even in wood-framed glazing products, the apparent and realistic numbers – the former based on centre-of-pane only – can differ by a factor of two. Most designers are unaware of this discrepancy.

(16)*High quality wood windows*

All 40 of the UK schemes, and 9 out of 10 of the post-1985 overseas schemes, have wood windows, ie 98% of all schemes. Given the standards which were aimed for, wood or aluminium-clad wood frames perform satisfactorily. In fact, in energy terms, they outperform the other frame materials on the UK market.

Scandinavian imported windows are more expensive than UK timber windows, but in part this reflects a more weatherproof design and a longer expected life, not just a better energy performance. In particular, one must question the practice of English speculative builders of building-in windows and placing them in the outer face of the wall. This practice is effectively forbidden by most importers of Scandinavian wood windows; it would void the warranty.

(17)*Lessons from earlier UK schemes*

The feedback from monitoring many of the older UK schemes, such as Salford, Two Mile Ash, and indeed Pennyland and Great Linford, contained many invaluable lessons for designers. However, despite a plethora of research papers, conferences, seminars, official reports, case studies and design guidance and project profiles, the amount of progress actually made in reducing energy consumption is limited. Twenty years after the Wates House and the first Strawberry Hill houses in Salford, many basic lessons from the past have not been incorporated into the most recent ultra-low-energy schemes.

(18)*Comfort standards*

These are very high. A whole-house temperature of over 21°C in midwinter is common. In dwellings which are highly insulated by UK standards, some occupants choose to maintain a winter air temperature as high as 24°C.

This very high thermal comfort standard negates some of the expected fuel saving. However, it also makes further reductions in heat loss, at the margin, more cost-effective.

(19)*Drying out*

In timber-frame homes, drying out was a minor event. By contrast, in ultra-low-energy masonry housing, behaviour in the drying out phase is totally different from the dwelling's experience in subsequent years. If more 'wet' techniques are used to ensure airtightness, in dwellings which subsequently only need a small space heat input designers will need to make much more allowance for drying out. This will apply especially in speculative houses and others which are built extremely quickly, or which have to be finished and closed-up in late autumn or winter.

(20)*Definition of autonomous/zero-energy homes*

There is some uncertainty about the dwellings which have a grid-connected photovoltaic (PV) system and produce as much energy as they consume over an annual cycle. Although such houses may consume little electricity, they take it from the grid mainly in winter and return it to the grid mainly in summer.

The value and source of marginal electricity varies from day to night and from summer to winter. It is generally more valuable by day, and at present the proportion of electricity from coal-fired plant is higher in winter.

Hence, the net CO_2 emissions caused by such homes are not straightforward. They may be less favourable than simple calculations indicate.

(21)*Electrical appliances*

The most energy efficient models of the major electrical appliances, eg the Gram LER-200 refrigerator, cannot be obtained in the UK. Householders are unlikely to go to the same lengths as the owners of Lower Watts and Southwell. They are more likely to take the easier route and to buy comparatively energy inefficient appliances.

There is a serious problem with the 'parasitic' power consumption of small electrical appliances. In some houses, this drain may exceed the consumption of a typical MVHR system.

(22)*Design-and-build*

Design-and-build (D&B) contracts are taking a growing share of the social housing market. It is currently close to 60%. Only one UK scheme out of 74, the Family Housing Association at Brixton, described in Phase 1, was D&B, but the point deserves close study.

D&B contracts seem to pose a serious obstacle to housing associations who wish to develop ultra-low-energy schemes. Several designers stated that while D&B could be satisfactory for conventional housing, it had proved almost incompatible with innovative, ultra-low-energy schemes. Clients' insistence on D&B had prevented at least two social housing developments from achieving the high levels of energy efficiency reported herein.

The scheme at 45-47 Cresswell Road, which is one of those reviewed in this report, could not easily be replicated because of today's pressure to use D&B. Some designers even believed that no cost saving was achieved by D&B, only a transfer of risk to contractors, who responded to this by raising their price.

(23)*Development control*

The planning system is expected to play a key role in delivering sustainable development, but the attitude of local planning authorities varies widely. In some cases, the UK's development control system is hindering improvements in energy efficiency. In a number of cases reported, planning permission was only granted in a way which worsened a house's energy performance. There were three such houses in the 40 profiles featured in Phase 1, and two in the 34 schemes which were noted at the end of Phase 1.

Hockerton, which was reviewed in Phase 1, saw a very different approach. This scheme was granted planning permission on a site where development would not 'normally' be permitted, conditional on exceptional energy efficiency and environmental standards. Given the magnitude of 'planning gain' when agricultural land receives permission for development, this effectively funded the entire overcost of the experimental measures.